
RIVERS AND COASTS -
YUKON COASTAL PLAIN

# GEOMORPHIC AND SEDIMENTOLOGIC PROCESSES OF RIVERS AND COAST, YUKON COASTAL PLAIN

by

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The data for this report were obtained as a result of investigations carried out under the Environmental-Social Program, Northern Pipelines, of the Task Force on Northern Oil Development, Government of Canada. While the studies and investigations were initiated to provide information necessary for the assessment of pipeline proposals, the knowledge gained is equally useful in planning and assessing highways and other development projects.

CONTENTS

Page

TABLES



MAPS IN BACK POCKET

Page

FIGURES

FIGURES

| FIGURES | | Page |
|---|---|---|

# 1. SUMMARY

## 1.1. Objectives of the Study

The primary objective of the study was to obtain reconnissance data about modern river and coastal environments for the Yukon coastal plain between the Mackenzie delta and the Alaskan border that would be of use in making decisions about future development in the area. Specific objectives can be conveniently divided into those concerned with rivers and those concerned with coasts.

### 1.1.1. River Objectives

The objectives for the river component of the study were:

1. To evaluate by various indirect methods the characteristics of the hydrologic regimes of the coastal plain rivers. Indirect methods were necessary because of the almost complete absence of systematic hydrologic data;
2. To infer long term trends toward aggradation or degradation in selected river segments from river long profiles, channel morphology and river deposits;
3. To obtain information on sediment types and on river bed and bank stability that would be useful in assessing the effect of man-induced disturbance on river regime;
4. To determine the influence of permafrost on channel flow and channel stability; and
5. In the context of the above, to identify those characteristics of arctic rivers which differ from rivers in more temperate locations and which might make arctic rivers a special case from a development point of view.

### 1.1.2. The Coastal Objectives

The objectives for the coastal component were:

1. To obtain as much data as possible on coastal retreat, from historical records and from 1944, 1951-54, and 1970 aerial photographs of the coast;
2. To examine broad patterns of sediment movement and storage in the near shore portions of the coastal zone and to investigate the processes affecting these patterns; and
3. To obtain data on distribution and variety of marine sediment types and their thicknesses in the coastal zone and on the position of the frost table in these sediment bodies.

## 1.2. Scientific Conclusions

### 1.2.1. Rivers

The main scientific conclusions resulting from the river study are:

1. Channel patterns of Yukon north slope rivers range from full meandering to braided. Wandering reaches are common and, because of their intermediate position between meandering and braided, are difficult to evaluate hydraulically without detailed

field measurements;
2. The rivers generally flow in their own alluvium, but they appear to be slowly downcutting, possibly in response either to present-day tectonic uplift or to decreased sediment supply;
3. Estimates of dominant (channel forming) discharges indicate that existing hydraulic formulas do not adequately describe the behavior of gravel rivers. They suggest, as well, that purely hydrologic methods of estimating flood discharges are unreliable, largely because of the absence of relevant input data;
4. Flow events of sufficient magnitude to cause appreciable bed scour, i.e. flows exceeding dominant discharge, can occur at any time during the open-water season;
5. Suspended load concentrations vary greatly during the open-water period but are directly correlated with discharge and are highest during spring break-up and during summer storm floods. Concentrations approaching 5000 mg./l. have been measured;
6. Assessment of bed scour is complicated by the influences of bed imbrication, ice jams, spring flow over ice, and frozen ground. Stones in the gravel beds of the channels are imbricated and offer considerably more resistance to erosion than their size would suggest. Because of this, lateral cutting of channel banks and localized erosion on bar surfaces may be the most common forms of scour in Yukon coastal plain rivers. Nothing is known, however, about the behaviour of channel beds during extreme flood conditions;
7. Lateral erosion may be locally severe, particularly where fine-grained floodplain sediments are exposed to thermal niching and block slumping. At one such location the bank of the Babbage River retreated 2.0 m. in a one-year period. On a larger scale, ground-ice slumps on valley walls expand rapidly (over 10 m. of headwall retreat in a one year period was measured at one location) and provide considerable sediment to the bordering river. Such slumps are not common on the Yukon coastal plain, however. Over the entire coastal plain, air photographs indicate few areas of rapid channel migration during the last 16 to 20 years;
8. Permafrost has a variety of effects on both river hydrology and channel stability. These include increasing the proportion of surface to total runoff, retarding bank erosion over short time spans, and adding to the relative importance of block slumping in channel migration. Permafrost beneath river beds could have serious implications for development.

### 1.2.2. Coast

The main scientific conclusions resulting from this coastal study are:

1. Coastal areas that have undergone the most pronounced general retreat in recent years are the area between Komakuk Beach and Alaska, the northwest, northeast, and southeast coast of Herschel Island, and the coast from Kay Point for a distance of 10 km. southeastward;
2. Sediment derived from coastal erosion and sediment delivered to the coast by rivers is dispersed along the coast by well developed systems of longshore currents. Longshore movement of sediment is

responsible for hundreds of metres of spit extension between 1952 and 1970. These currents transport sediment to three main sediment sinks in the Yukon coastal zone: (a) between Herschel Island and the mainland, (b) Phillips Bay, and (c) Shoalwater Bay;

3. Ice-push did not exert a major influence on the shore zone in 1972;
4. Silt carried to the coast by rivers is stored in deltas of the Babbage River and Blow River types, whereas clay is carried directly offshore. Silty sediments in the upper parts of these deltaic bodies are rich in excess ice;
5. Frost tables in mid-July, a month after break-up, are only a metre or less beneath the surfaces of gravel spits and intertidal sand bars and beneath the bottoms of deltaic distributary channels that are as deep as 5.8 m.; and
6. Gravels in the shore and near-shore zones contain resistant pebbles and may locally be as thick as 8-9 m. but are probably more generally 4 m. or less in thickness.

## 1.3. Implications and Recommendations

### 1.3.1. Rivers

1. An impermeable permafrost layer beneath the river beds and banks may inhibit catastrophic changes in channel morphology while at the same time leading to thermal niching and block slumping as the major processes of lateral channel migration.
2. Rivers of the Yukon coastal plain should provide no serious obstacle to pipeline activity if construction practices take the following factors into account:
   (a) Destruction of surface vegetation on the river banks will permit the active layer to thicken. Where river banks contain fine sediments with a high ice content, melting, slumping, and major erosion of the river bank could result;
   (b) Disturbance of the natural imbrication of stones in the river bed will temporarily reduce the ability of the bed to resist scour;
   (c) Construction during the late autumn or winter when flow is low will enable construction to be completed and the channel returned as nearly as possible to its natural form without interference from major flow events. In addition, the downstream effects of construction such as increased suspended load would be minimized because of the low capacity of the flow to move sediment. Migration and spawning schedules of fish will, however, have to be considered; and
   (d) A pipeline buried beneath the river bed could create a thermal disturbance by thawing frozen material (hot pipeline) or by freezing unfrozen material (cold pipeline). In either case, local aufeis may develop. This could dislocate the pipe and localize intense river-bed and -bank scour at the pipeline crossing.
3. Most rivers of the Yukon north slope have beds of pebble or cobble gravel. Clasts are generally quartzitic and resistant, although much of the sand and granule fraction in the Babbage River basin is composed of shale. From a geomorphic point of view

limited use of river gravel for construction purposes could be considered, keeping in mind: (a) that the major bed-movement events associated with dominant or larger discharges will periodically re-establish the local bed elevation and bar pattern; (b) that removal of gravel at some localities and under some circumstances could adversely affect the spawning and migration of fish; and (c) the possible occurrence of frost beneath the beds of the shallow rivers of the Yukon coastal plain could complicate plans to excavate gravel from the river beds.

### 1.3.2. Coast

1. Insofar as the coastal zone is used for staging areas or for shore installations, the dynamics of the shore area must be taken into account. Either coastal retreat or accumulation could jeopardize the success of such an operation. Any interruption of the longshore drift pattern will have feedback both up and down the coast that will disturb the natural balance. This is not to say that the effects would necessarily be harmful, but they should be anticipated.
2. The Babbage, Blow, and Running river deltas have a high silt content and their sediments are rich in excess ice. Thermal disturbance of these areas could lead to considerable thaw consolidation. In addition to this, thermokarst lakes on flat deltaic plains tend to be favoured by wildfowl for nesting purposes. In 1972 the Babbage delta was a major nesting area for whistling swans.
3. Thermokarst lakes on the extensive flat surfaces of the Babbage and Blow river deltas lie below the level of storm surges along the coast. They are also important nesting areas. Oil from a spill could be spread into these lakes during a storm tide, with serious ecological consequences.
4. Lagoons behind spits and offshore barrier islands are common along parts of the Yukon coast. These could prove to be useful natural containers for spilled oil if it is possible to divert oil into them. Shore storage of large amounts of oil could also be located behind such lagoons.
5. Active gravel and sand bodies in the shore and near-shore area could be useful sources of contruction material. If the alternative is establishing an overland route for several kilometres to pit a "fossil" gravel body at some distance from the shore and thereby leave permanent scars on the landscape, it would seem preferable both economically and environmentally to remove gravel for a nearby "living" environment that can repair the damage done. Because many, but not all, spits are important nesting areas, because perforating a spit could set up an instability that could destroy it, and because existing gravel supply in longshore currents is insufficient to repair certain spits and beaches, selection of a locality for a pitting operation would have to be made very carefully and only after detailed study of a particular proposal. However, such pitting operations might well create less disturbance than certain natural calamities, such as storm tides, from which the environment manages to recover.

## 2. INTRODUCTION

### 2.1. General Nature and Scope of Study

The primary objective of the study was to obtain, for the Yukon coastal plain between the Mackenzie delta and the Alaskan border (Map. No. 1), reconnaissance data about modern river and coastal environments which would be of use in making decisions about future development in the area. Considerable emphasis was placed on determining the importance of sediment erosion and accumulation, both present and potential, and on identifying the factors which control these processes.

The project consisted of two main phases:

(a) Field - the authors spent eight weeks in the field, observing, sampling and establishing benchmarks against which future change can be measured; and

(b) Office - measurements for various purposes have been made from topographic maps and aerial photographs, and sediment samples and field data have been analyzed.

### 2.2. Specific Objectives

Specific objectives can be conveniently divided into two parts: those concerned with rivers and those concerned with coasts. Substantial portions of the report which follows will be similarily divided.

#### 2.2.1. Rivers

The objectives for the river component of the study were:

1. To evaluate by various indirect methods the characteristics of the hydrologic regimes of the coastal plain rivers. Indirect methods were necessary because of the almost complete absence of systematic hydrologic data;
2. To infer long term trands toward aggradation or degradation in selected river segments from river long profiles, channel morphology and river deposits;
3. To obtain information on sediment types and on river bed and bank stability that would be useful in assessing the effect of man-induced disturbance on river regime;
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#### 2.2.2. Coast

The objectives for the coastal component were:

1. To obtain as much data as possible on coastal retreat, from historical records and from 1944, 1951-54 and 1970 aerial photographs of the coast;
2. To examine broad patterns of sediment movement and storage in the nearshore portions of the coastal zone and to investigate the processes affecting these patters; and

3. To obtain data on distribution and variety of marine sediment types and their thicknesses in the coastal zone and on the position of the frost table in these sediment bodies.

## 2.3. Relevance to Pipeline Development

The most dynamic aspects of the Yukon coastal plain with which pipeline development must contend are those involving the hydrologic regimen, the thermal regimen, and sediment erosion and deposition in the modern river and coastal environments. Sediment movement can lead to rapid undermining or burial of an installation and to its failure unless design features take these processes into account. Clean-up procedures for spilled oil can benefit greatly from an appreciation of the active environment.

The susceptibility of an area to erosion or deposition can best be determined from systematic, long term observations of the magnitude involved. Of particular importance is evaluation of the role of extreme events, for example a major storm or flood. A short term study such as this can, however, be of some use: active processes can be identified, the morphology of various features can be used to infer their history, and historical data, including aerial photographs, can give some information on the magnitude/frequency problem.

These aqueous environments are important not only because of the effects which they might have on an installation but because of the effects, both direct and indirect, which the installation might have on the environments themselves. These environments are critical to the swimming and wildfowl components of the ecosystem and will provide the water supply and perhaps even construction materials for development projects. The effects of construction and of sand and gravel removal for construction cannot be evaluated without knowledge of the active geomorphic and sedimentologic processes.

## 2.4. Acknowledgements

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Photogrammetric meassurements of coastal change were made by Mrs. G. Mizerovsky and have proved to be an important component of the study. Many of these measurments have been plotted on photo maps provided for this project by the Photo-mapping Unit of the Topographical Survey Directorate. G.W. Kite, Inland Waters Directorate, Department of Environment, prepared the flood-frequency estimates based on the grid-square method. K. Stewart, Inland Waters Directorate, assisted in digitizing work on the river basins. Thanks are due for sediment analyses to R.G. Kelly and D.E. Field of the Geological Survey of Canada Sedimentology Laboratory and to Wm. Stichling, Sediment Survey Section, Inland Waters Directorate. Members of the International Boundary Commission kindly made available

early survey records from the 1912 survey. Members of the Royal Canadian Mounted Police have provided details from their Archives about the G. Wiik grave-marker at King Point. Assistance in compiling and illustrating this report was offered by R. Frederick, D. Given, H. Kerfoot, D. Kurfurst, F. Schnay C.J. Ulmann, and the photographic Section of the Geological Survey of Canada.

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## 3. CURRENT STATE OF KNOWLEDGE

Geomorphic and sedimentologic studies of the Yukon coastal plain area are few. Background meteorologic and hydrologic data are also sparse. Fortunately, considerably more work has been accomplished in the neighbouring Mackenzie delta and Alaskan coastal plain areas.

Temperature and precipitation records have been kept at Shingle point and Komakuk Beach since 1958 and at Stokes Point between 1958 and 1963. Systematic hydrologic measurements on rivers are effectively non-existent, though discharge records from a gauging station installed on the Firth River (Map. No.1) in April, 1972 have been made available by the Water Survey of Canada. Sea-ice records for this portion of the Beaufort Sea coast are available back to 1953 in Canadian Department of Transport reports. Abrahamsson (1966) has briefly discussed selected aspects of the climatology and surface hydrology of part of the coastal plain and a useful compendium of information on waves, tides, ice islands, storm surges, and the effects of the 1970 storm has been produced by the Canadian Department of Public Works (1971).

Church (1971), in a map and air photo study, has commented on the hydraulics and morphology of Yukon coastal plain rivers. Geomorphic processes on the Blow River delta have been discussed by Walker and McCloy (1969) and by McCloy (1970). Mackay (1963) has reported on coastal retreat near Kay Point, King Point, Sabine Point, Running River delta and Herschel Island.

Surface materials on land and features of the glaciation have been mapped (Hughes, 1972; Rampton, 1970, (in press)), as has the offshore distribution and thickness of Recent mud (Shearer, 1972). Pelletier and Shearer (1972) have reported linear depressions on the sea bottom that they attributed to the scour action of grounded but still moving ice floes.

## 4. STUDY AREA

### 4.1. Physiography

The Yukon north slope can be divided into two major physiographic components (Bostock, 1970):

(a) Yukon Coastal Plain - This is an area of low relief (Figure 1) that lies between the Beaufort Sea and the mountain front. Its altitude ranges from sea level up to about 150 m. It extends westward from the Mackanzie delta to the Alaska border. Its width varies from 5 km. near the Alaska border to 30 km. in the Babbage River basin; and

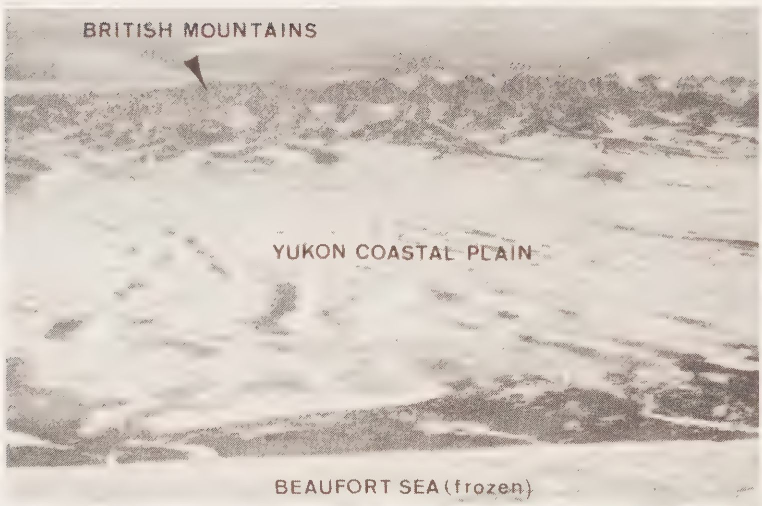



Figure 1. View south across Yukon coastal plain, west of Komakuk Beach. (8 June 1972; GSC 202262 - L)

(b) Cordilleran Region - This mountainous area includes, from northwest to southeast, the British Mountains, the Porcupine Plateau in which is located the Barn Mountains, and the Richardson Mountains. Along the drainage divide altitudes reach 2,000 m. ASL in the British Mountains and 1,700 m. ASL in the Richardsons.

Rivers rise in the mountains and along the mountain front and flow northward across the coastal plain to the Beaufort Sea.

## 4.2. Climate

The climate is severe; summers are short and cool and winters long, cold and dry. Figure 2 contrasts summary data for Old Crow, south of the British Mountains, with Shingle Point and Komakuk Beach on the Beaufort Sea Coast.

The temperature extremes along the coast are somewhat ameliorated by the influence of the sea. However, for only four months in the summer, June through September, is the mean temperature above freezing. February is the coldest month of the year on the coastal plain; mean temperatures then are about $-28^{\circ}C$. The ground is permanently frozen to considerable depth and the maximum thickness of the active layer is generally in the order of a metre. Precipitation is low throughout the year and reaches a maximum of about 4 cm. in the month of August.

Hydrologically, the most significant aspect of the atmospheric circulation is that the mean summer position of the arctic front is near the Yukon north slope (Reed and Kunkel, 1960; Bryson, 1966). Cyclonic waves moving east along this front produce most summer rains (Hare, 1969).

## 4.3. General Geology

For a more detailed account of the geology of this region, the reader is referred to Rampton (in press).

Norris et al (1963) describe the rocks of the British Mountains as primarily non-metamorphosed argillites and sandstones of the Precambrian or Cambrian Neruokpuk Formation, although some lower Mesozoic limestone and clastics are present. The Peel Plateau and Richardson Mountains are underlain by Mesozoic shale, quartzitic sandstone, and limestone. These rocks have been folded and faulted most recently during the Laramide orogeny of late Cretaceous age.

These rocks also underlie that portion of the coastal plain, about half its width, that lies adjacent to the mountain front. The rocks here have been truncated and form a distinctive pediment surface. The pediment is thinly mantled by gravel and other unconsolidated sediments.

The seaward half of the coastal plain is underlain by unconsolidated Quaternary sediments that average more than 30 m. in thickness. These sediments are of stream, lacustrine, marine, and glacial origin.

The limit of glaciation has been mapped by Hughes (1972) and is shown on Map No. 1. Glaciers of early Wisconsin or pre-Wisconsin age evidently flowed down the Mackenzie Valley, lapped over the coastal plain, and lay against the mountain front as far west as the Firth River valley. Herschel Island is composed of glacially deformed sediments. Submarine ridges 8 to 10 m. high that are 30 km. long and lie parallel to the coast 5 to 10 km. offshore from Komakuk Beach (Can. Hydrographic Chart 7650) may be lateral moraines marking the continuation of the glacial limit offshore.

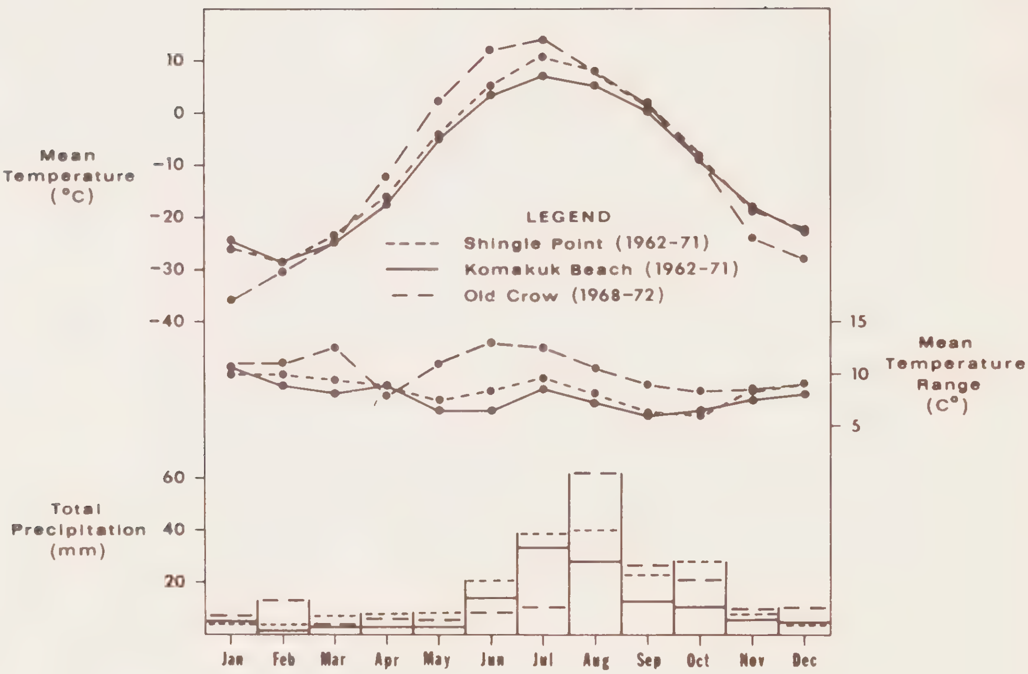



Figure 2. Summary climatic data.

The crests of these ridges are more than 13 m. below sea level.

Gravel in the river beds on the Yukon north slope consists mostly of resistant pebbles and cobbles of quartzitic sandstone. The sand and granule fractions are also quartzitic except in the Babbage River basin where they contain an abundance of soft shale. Axial ratios of stones are fairly consistent at about 3:2:1 (long: intermediate: short).

The effects of eustatic, isotatic, and tectonic factors on the evolution of the north slope rivers are difficult to separate. Worldwide lowering of sea level during glacial maxima, the most recent being about 15,000 to 18,000 years B.P., would lower base levels for the rivers and permit incision of their valleys. This would be accentuated by isostatic uplift of land accompanying removal of the weight of water from shelf areas. Arrival of glaciers on the coastal plain would counteract this by producing isostatic depression, but the glaciers would also block the north-flowing rivers and either divert or pond the water. Subsequent deglaciation with eustatic sea level rise would reverse this process and probably lead to a filling in of the river valleys with alluvium. This simple model would have to be tested locally for each river because it presupposes that the offshore submarine gradient at that time exceeded the seaward slope of the land surface. Superimposed on this complexity is the possibility that tectonic forces have also introduced vertical instability. There is some geomorphologic evidence that indicates present-day uplift, and this will be more fully developed in the discussion of river morphology.

## 5. SOURCES, METHODS, AND RATIONALE OF DATA COLLECTION

The primary data used in this study were gathered during an eight week field season in July and August 1972 and a one week visit in July 1973. These data have been augmented by air photo, map, and laboratory analyses. The purpose of this section of the report is to detail the specific types of information collected, the methods by which this information was obtained, and the uses to which it has been put.

### 5.1. Rivers

Fluvial landscapes can be studied at a number of scales. The basic unit of such landscapes is the drainage basin, and the properties of a basin upstream from a given river section determine in large part the hydraulics and morphology of that section. Within a drainage basin, the form of river valleys reflects both the processes which supply sediment to the channels in the valleys and the history of those channels. As well, the morphology and sedimentology of the channels, themselves, provide information on the hydraulics of the flows which create, maintain and modify them.

The three scales considered in the river component of this report, then are those of the drainage basin, the river valley, and the channel section.

#### 5.1.1. Drainage Basin Characteristics

In addition to general observations on physiography and geology, values of several morphometric properties have been determined for the Yukon north slope drainage basins. The nature of these properties and the

possible hydrologic implications of variations in them are discussed below. A simple model based primarily on basin area and on estimated climatic extremes is used to provide peak flow estimates for selected river sections.

### Area

The property which probably most directly affects river discharge is the surface area of its drainage basin. Basin size affects not only the amount of surface runoff but also the distribution of runoff with time, and thus peak discharge. Runoff originating in the most remote portion of a large basin may arrive at the outlet too late to contribute to the peak flow (Chow, 1964)

### Shape

Discharge characteristics are also affected by basin shape. Long narrow basins can be expected to have attenuated flood peaks because the time of arrival of runoff at the outlet will be very different for runoff originating from different parts of the drainage basin. The dimensionless circularity ratio, Rc, can be defined as the ratio of basin area to the area of a circle having the same perimeter length as the basin (Miller, 1953). For a circular basin Rc = 1.0; the more elongate the basin (one form of non-circularity), the lower the value of Rc.

### Hypsometry

A hypsometric curve is a cumulative-frequency curve of, in this case, the percentage of total basin area above each elevation in the basin. To facilitate comparison of basins the hyposometric integral is defined as the ratio of the area beneath a hypsometric curve and the total rectangular area bounded by its axes (Strahler, 1952). Note that the hypsometric curve does not give the mean slope of a drainage basin at any elevation. Slope is dependent upon the length of a contour band as well as on the area of the band.

Characteristic hypsometric curves are shown in Figure 3. In the "youthful" basin, a large proportion of upland surface has not yet been transformed into valley-wall slopes. The "mature" basin has narrow drainage divides with little remaining of the original surface. The "monadnock" phase of Figure 3. illustrates the curve for a basin with generally low relief but prominent erosion remnants.

The distribution of area with elevation, ie. the hypsometry, can play an important role in determining the form of a river's discharge hydrograph when snowmelt is a major component of total runoff. A "mature" basin can be expected to have a flatter hydrograph than the "monadnock" or "youthful" types. In these last two types a large proportion of the total area lies within a narrow elevation range and, assuming no interference from other factors, maximum rates of snowmelt will occur at the same time over most of the basin.

### Hydrograph estimation

In addition to flow estimates at particular reaches, based on data measured in the field, flood frequencies of Yukon north slope rivers have been investigated using two methods that relate physiographic

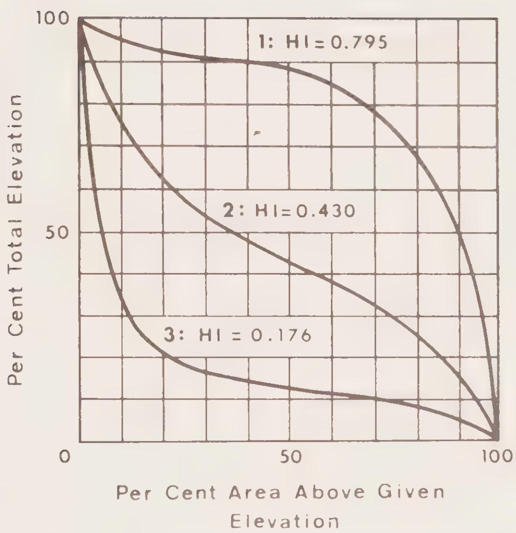



Figure 3. Characteristic drainage basin hypsometric curves (after Strahler, 1952).
(1) Youthful stage
(2) Mature stage
(3) Monadnock phase

HI = hypsometric integral

characteristics of the drainage basin to river-flow parameters in that basin.

(a) Many of the methods used to estimate peak flows in regions where few discharge records are available are variations on the so-called rational formula (Chow, 1964):

$$Q = CiA$$

where
$Q$ = peak discharge (m.$^3$/sec.)
$C$ = coefficient which depends on characteristics of the drainage basin
$i$ = precipitation intensity (m./sec.)
$A$ = drainage area (m.$^2$)

This formula has been applied by Church (1971) using a precipitation intensity of 0.075 m. in 24 hr., to the prediction of "maximum probable" floods along a proposed route for a Prudhoe Bay - Edmonton oil pipe line.

Other factors being equal, large drainage basins tend to be less sensitive to high intensity rainfalls of short duration than small ones because of the effect of channel storage. The rational formula does not take channel storage into consideration and Dalrymple (1964) recommends that its use be restricted to areas of less than one km$^2$. Church (1971) attempts to overcome this restriction by weighting the rational coefficient according to basin area.

$$C = 2^{(7.413 - \log A)}$$

He suggests that "the procedure appears to overestimate for basins of moderate size, and to underestimate for some large basins, but at most by a factor of about two.

(b) A modification of the grid-square method was also used to estimate flood frequencies on the Yukon coastal plain. The grid-square method (Solomon et al, 1968; Solomon and Qureshy, 1972), utilizes a computerized data bank of some 18 physiographic characteristics that are filed on a 10 X 10 km. square grid system, and the closest systematically measured meteorologic and hydrologic parameters available, to estimate mean hydrologic and meteorologic parameters at ungauged locations.

### 5.1.2. River Valleys

River valleys can include a number of components. The valley walls separate the upland surface from the highest alluvial terraces. They can be very steep and are often the site of active mass movements. Their height and steepness may suggest channel incision and long-term degradation. The number, width and continuity of high terraces are also related to river stability. Both paired and unpaired terraces may be produced by repeated episodes of alluviation and entrenchment. The risers, or steep fronts, of these terraces are effectively segments of the valley wall and are susceptible to mass movement processes.

The valley plain is the lowest terrace, sometimes the flood plain, if one exists. Identification of a flood plain is usually made possible by some information on frequency of inundation (Wolman and Leopold, 1957). On many rivers, the flood-plain level can be exceeded by several floods each year. A low terrace, on the other hand, will be flooded much less frequently, let us say less often than the 2.33 year return period of the mean annual flood. In the absence of flood-frequency data it is difficult to determine whether the valley plain bears an equilibrium relationship to present runoff characteristics, in which case it would be a true flood plain, or whether it is an alluvial terrace being progressively abandoned by a degrading channel. In either case, such a surface may have been a flood plain in the recent past and thus be underlain by fine-grained

sediments due to overbank flooding. Valley plains may contain relict landforms or vegetation patterns which relate to the lateral migration of a river channel.

The active channel is the fourth component of river valleys and is discussed in the next section of this report.

Observations on river valleys were primarily descriptive and intended only to provide an indication of the kinds of features which might be encountered along a given river. The nature of the descriptive observations are detailed in Table I. As well, hammer seismic work was carried out on the valley floors at several locations to determine the thickness of alluvial fill.

### 5.1.3. River Channels

The basic unit of data collection was the river reach. Within the constraints imposed by field logistics, the major rivers were sampled according to the following principles:

(a) That downstream changes in river morphology and hydraulics be studied on at least several rivers;
(b) That sites already proposed as possible pipeline crossings be examined; and
(c) That obvious sites of recent channel instability be inspected.

General observations on channel pattern, material in channel and bank, and lateral and vertical stability (Table I) were combined with the collection of cuantitative data on selected reaches. Study reaches were chosen that were relatively straight, of relatively constant width, and relatively free of local flow peculiarities.

The following data were collected at each reach (see Appendix):

(a) present water discharge - using a rubber boat and current meter;
(b) suspended sediment sample - using a US DH48 depth-integrating sampler;
(c) water temperature - using a Wheatstone bridge and thermistor sensor;
(d) water-surface slope - using Zeiss Ni-2 level;
(e) valley-plain slope, if possible - using Zeiss Ni-2 level;
(f) channel geometry - based usually on five surveyed cross-sections;
(g) channel bed and bank material - intermediate axes of clasts > 8 mm. diameter were measured with a sample size of 300 to 500; These clasts were collected along grid transects - the "grid-by-number" method of Kellerhals and Bray (1971); samples of fines were collected for laboratory analysis; and
(h) detailed notes and photographs were used to record valley and channel characteristics. Slope of the valley plain was also measured from available topographic maps (so-called "map slope" in Appendix). Enough basic data per reach for reconnaissance purposes could be collected in 4 man-days and, in all, 16 reaches were examined in the field. Most work was done on the Babbage, Blow and Firth rivers, the largest in the area, but reaches on the Malcolm, Running, Rapid and Big Fish were also examined (Map No.1).

Table 1

Yukon North Slope River Study - Air Photo and Field Check-list

## I. River Valleys

A. Valley Type
   1. Flood plain
   2. Outwash plain
   3. Erosional channel
   4. Alluvial fan
   5. Delta

B. Valley Walls
   1. Type: none obvious, single slope, terraced
   2. Riser slope: vertical, steep ($>15^o$), gentle ($<15^o$), variable
   3. Material: bedrock, gravel, sand, silt-clay, composite
   4. Vegetation: a. Coverage
      b. Type: trees, shrubs, herbs

C. Terraces
   1. Number of levels, if any
   2. Width of each level
   3. Continuity: indefinite, fragmentary, continuous
   4. Material: see B.3. for details
   5. Vegetation: see B.4. for details

D. Valley Plain - floodplain or low terrace
   1. Width, if present
   2. Continuity: see C.3. for details
   3. Floodbasins: none, swamps, lakes
   4. Material: see B.3. for details
   5. Vegetation: see B.4. for details
   6. Relict features: channel banks, oxbows, meander scrolls, braid scars, other

E. Mass Movement
   1. Type: none, wash, creep, solifluction, slump, slide, flow, fall, other
   2. Location: valley plain, terraces, terrace risers, valley walls
   3. Extent
   4. Active/Inactive

F. Frozen Ground Features
   1. Type: none, massive ground ice, ice wedges/polygons, pingos, thermokarst, other
   2. Location: see E.2. for details
   3. Extent

G. Miscellaneous

## II. River Channels

H. Channel Pattern
   1. Straight
   2. Tortuous meanders (thalweg azimuth changes by $>180^o$)
   3. Scroll meanders (unconfined and regular)
   4. Truncated meanders (confined by valley walls)
   5. Wandering (two-phase channel: either meandering at high flows and faintly braided with point bars at low; or braided with dominant low water channel)
   6. Anastomosing (multiple channels with stable islands)
   7. Braided (multiple channels with unstable islands)

I. Channel Deposits
   1. Type: none, point bars, side bars, mid-channel bars, diagonal bars, natural levees, other
   2. Material: see B.3. for details
   3. Vegetation: see B.4. for details

J. Channel Banks (Non-Depositional)
   1. Type: a. Alluvial: formed in flood plain, delta plain, alluvial fan, river terrace, other deposits
      b. Other unconsolidated: formed in marine, lacustrine, glacial, colluvial, aeolian, other deposits
      c. Bedrock
   2. Material: see B.3. for details
   3. Vegetation: see B.4. for details

K. Channel Bed
   1. Material: see B.3 for details
   2. Bed forms: a. Type
      b. Size, spacing
   3. Depth to bedrock
   4. Miscellaneous (eg. anchored vegetation, aufeis)

L. River Lateral Activity
   1. Type: none, irregular, cut-bank/point bar, cut-offs, avulsions, crevasse splays, other
   2. Bank stability: stable, localized erosion/slumping, moderately unstable, highly unstable
   3. Bank failure type: particle erosion, block slump, detachment creep, debris flow, other

M. Channel Vertical Stability
   1. Stable: definitely, probably
   2. Degrading: definitely, probably
   3. Aggrading: definitely, probably

N. Miscellaneous Measurements
   1. Estimated bankfull channel width
   2. Meander wavelength
   3. Meander belt width
   4. Sinuosity ratio

Based partly on information from: M.A. Church, University of British Columbia, Personal communication; Mollard (1973); Bray and Kellerhals (1972); Am. Soc. Civ. Eng. (1971); and Allen (1965)

### 5.1.4 River Hydraulics and Discharge Estimation

Most river channels of the Yukon north slope have coarse, clastic boundaries (Table VI). Such channels usually have high width-depth ratios. Sediment is transported primarily as bedload, and channel beds are armoured because of selective transport and material imbrication (Church, 1972). Henderson (1966) suggested that their form is controlled by conditions obtaining at the threshold of motion. Below the channel-forming or dominant discharge the rivers are fixed-bed; above it, heavy bed load transport causes a sharp decline in boundary resistance and velocity increases much more rapidly than in rivers with finer bed material (Church, 1972).

Indirect estimation of discharges up to and including dominant discharge have been made using formulas that assume steady, uniform flow and no significant bed-material transport. Above dominant discharge "live-bed" conditions prevail and there are no reliable hydraulic methods of indirectly determining discharge in gravel-bed rivers.

Three uniform flow equations (Table V) were applied to low-flow data collected at each of the study reaches. Predicted mean velocities were compared with those measured in the field to determine which equation could most reliably be used to estimate dominant velocities and discharges.

The water level associated with dominant discharge is usually equated to a channel-filling or bankfull stage (Henderson, 1966). For many rivers this is the stage of incipient overflow onto a flood plain (Wolman and Leopold, 1957). On gravel-bed rivers however, the floodplain often is not a distinct unit. Rather, it grades into the channel bed and, therefore does not provide an easily definable level. The definition of bankfull stage adopted for this study - the average level of the highest bar surfaces whose primary plant cover does not include shrubs or trees - represents an attempt to achieve some objectivity but its physical meaning is uncertain.

Measured channel characteristics at bankfull stage were used in the selected uniform-flow formula to obtain estimates of dominant discharge at each study reach. Where possible these estimates were compared to discharges based on Carlston's (1965) meander wavelength equation:

$$Lm = 8.2\ Qb^{0.62} \qquad \text{(British units)}$$

Values of meander wavelength were obtained by taking the mean of 6 to 8 measured wavelengths along a length of river which included the field study reach.

Under dominant discharge conditions the bed material of a channel should be just at the threshold of motion. Threshold grain sizes - the grain size of a uniform bed which would be at the threshold of motion under dominant discharge conditions - based on Neill's (1967) criterion:

$$\frac{\left(V_m^{\,2}\right)}{g\left(\frac{\rho_s - \rho}{\rho}\right)D} = 2.5\left(\frac{\bar{d}}{D}\right)^{0.2}$$

were compared with measured $D_{84}$ sizes. Although the necessary assumption of uniform bed material size cannot be met, this criterion provides a test of the reasonableness of the uniform-flow formula dominant discharge estimates.

### 5.1.5. Sediment Transport

At discharges above dominant, general movement of bed material will occur. In gravel-bed rivers a very few high flow events commonly move a high proportion of the total annual sediment load (Henderson, 1966; Church, 1972).

#### Bedload

Most sediment in rivers of the Yukon north slope is probably moved as bedload. No direct measurements of transport rates are available and there are at present insufficient data for indirect computations to be made. Data collected on bed scour do relate to the competence of north slope rivers to move the material on their beds, however. This is discussed in Section 5.1.6.

#### Suspended and dissolved load

Both suspended and dissolved loads tend to increase with increase in discharge. Because no systematic data have been collected on north slope rivers, depth-integrated water samples were obtained as part of the data collection program at each field study reach (see Section 5.1.3). Although of very limited use, the sediment concentrations of these samples do provide some information on the range of values which might be encountered on the north slope.

### 5.1.6. Channel Stability

During high flow events, erosion of both bed and bank material will occur. Where possible, observations relating to bed scour and channel bank and bar stability were made at the study reaches.

#### Bed scour

The intensity and distribution of scour in gravel-bed rivers are affected by a number of factors. Some of those listed below are peculiar to Arctic rivers:

(a) particle size and sorting;
(b) bed imbrication;
(c) macro-eddies caused by channel configuration;
(d) whether or not spring flood is over bottom-fast ice;
(e) ice push; and
(f) the proximity of the frost table to the channel bed.

The complex relationships among the above factors have prevented the formulation of reliable criteria for indirectly assessing scour in arctic gravel rivers. Some direct measurements have been attempted, however. Scour chains (Figure 4.) and painted gravel lines (Figures F1: B and BL5: 5B in Appendix) established during the summer of 1972 were revisited in July 1973.

#### Lateral stability

Channels shift by avulsion - common on braided rivers

Figure 4. Scour chain on gravel bar; Firth River, reach F1; scale is 1 m. long. (16 July 1972; GSC 202262 - P)

(Church, 1972) - or by preferential erosion along one bank. Bank erosion results either from exceeding the tractive force required to entrain bar gravel, or from thermo-erosional niching and block failure of frozen fine sediments.

Comparison of air photographs from the early 1950's with those from 1970 has provided some information on channel shifting on coastal plain rivers. As well, stakes placed on one study reach on 15 June 1972 and revisited on 25 July 1972 and on 22 July 1973 have provided bank retreat data in an area of semi-cohesive floodplain material which is particularly susceptible to floodplain niching and block slumping. Retreat measurements have also been made for the headwall of a ground-ice slump which borders a study reach on the Babbage River.

## 5.2. Coast

The general patterns of erosion and sedimentation along the coast were studied in order to gain some impression of the types, rates, and relative importance of processes active on various parts of the coast. Observations were made of the distribution of shore sediment bodies, whether spits, beaches, etc., the sediment types in them, and what their configurations indicated about such aspects of sedimentation history as longshore drift direction, influence of ice push, and influence of storm tides.

Cross-sections of particular shore features, such as spits and beaches, were surveyed to serve as examples of a whole class of features. Some surveys were made with a Zeiss Ni-2 level and rod and others were made with hand level and tape.

Frost tables were located by probing with a 1-cm. diameter stainless steel rod one metre long with a sharpened tip. Probes at each site along a profile were repeated until two or more indicated the same frost depth to within 5%. This avoided errors due to the probe hitting stones at depth. In some cases, pits were dug to confirm the presence of frost.

Near-shore bathymetry and sub-bottom data were obtained using a Raytheon RTT-1000 Survey System mounted on a 16-foot rubber boat. The RTT-1000 uses a 2- channel strip chart recorder that records reflections from 200-KHz. and 7-KHz. transducers. The former, with a $3^{\circ}$ beam, gave high resolution of features at the sediment-water interface and the 7-KHz. transducer provided sub-bottom reflections, giving local indication of stratification and position of the frost table. This system was extensively used in the area of the Babbage River delta, Phillips Bay, and Kay Point (Map No.4), and off the mouth of the Firth River fan delta (Map No.6). A few bottom samples were taken with a can mounted on a rod and hand held.

Four holes were drilled to depths of 3-4 m. in the Babbage River delta and samples recovered with a split-spoon sampler.

Hammer seismic profiles were run on the Babbage River delta and on the spit south of Kay Point to aid in the stratigraphic interpretation of these features.

## 5.3. Laboratory Techniques

Granulometric analyses of channel- and sea-bottom samples and surface material samples have been made by a standard sieve/pipette technique in the Geological Survey of Canada sedimentation laboratory. Measurement of suspended and dissolved sediment concentrations were made by the Sediment Survey Section, Inland Waters Directorate, Department of Environment.

Hypsometric and longitudinal profile measurments of river basins and river channels were made from 1/250,000 and 1/50,000 topographic maps using a D-Mac Pencil Follower, and the digitized record processed by CDC-6400 computer.

All photogrammetric measurements of coastal change have been made by Mrs. G. Mizerovsky. Continuous tone negatives made from laydowns of the 1952-54 aerial photographs were printed at 1/25,000 for Herschel Island and for the coast between the Spring River delta (138°35'W) and King Point. The 1970 photographs were reduced to 1/25,000 for direct comparison as were those vertical photographs from the 1944 trimetrogon series that traversed the coast. Individual changes shown numerically on the maps are thought to be accurate to within ±15 m. although in most cases the measurements show a consistent trend that indicates a reliability to within about 5 m. Erosion figures on Maps No. 3,4,5, and 6, and on Figures 39 and 43 apply to the shoreline position so include beach changes as well as retreat of the coastal cliff.

## 6. RESULTS

### 6.1. Rivers

#### 6.1.1. Drainage Basin Characteristics

The names, locations and basin areas of major north slope rivers are given in Table II. The drainage basins are outlined on Map No. 1. Most of them extend across physiographic regions. The rivers originate in the mountains which parallel the Beaufort Sea coast, cut through the pediment surface which fronts these mountains in many areas, and move across the low lying, usually hummocky, Yukon coastal plain.

##### Area

By far the largest of the drainage basins are those of the Firth (6200 km.$^2$), the Babbage (5,000 km.$^2$) and the Blow (3,700 km.$^2$) rivers. Accordingly these were given greatest emphasis in both the field and office programs. They are not only large but illustrate well the range of channel types found in the coastal plain segment of the Yukon north slope. The large Firth and Malcolm rivers flow northeastward behind the most northerly mountain range so that the western segment of the coastal plain is influenced only by rivers of relatively small drainage area.

##### Shape

Values of the circularity ratio (Table II) range from 0.261 for Deep Creek to 0.674 for the Backhouse River. The Firth (0.273) is much less circular than either the Babbage (0.414) or the Blow (0.420). Interestingly, the Babbage tributaries are much more elongate than the parent basin.

The magnitude and duration of flood waves in a river reach will be strongly affected by the circularity of the contributing drainage basin. Deep Creek, for example, can be expected to have relatively flat storm event hydrographs and the effects of a storm will last a relatively long time. Of the major north slope basins, the Babbage and Blow rivers should have higher flood peaks of shorter duration than those of the Firth

assuming, of course, that other relevant factors are constant for the three basins.

## Hypsometry

Maximum basin elevation is highly variable (Table II). Rivers heading in the Alaskan sector of the British Mountains such as the Firth (1780 m.) and the Malcolm (2000 m.) show much greater relief than the Running River (905 m.) or Deep Creek (533 m.) which begin in the more subdued Barn Mountains.

Hypsometric integrals for some of the basins are listed in Table II. Hypsometric curves for rivers in the Blow and Babbage drainage basin (Figures 5 and 6) tend in form toward that of the "monadnock" phase of Figure 3. This type of curve is not common. In this case it appears to result from the abrupt boundary between mountains and coastal plain which characterizes the north slope basins. The Crow and Trail rivers, tributaries of the Babbage, most closely approach the "mature stage" because only a relatively small proportion of their basins falls into the coastal plain physiographic region.

These facts are most important because of their hydrological implications. It may be possible to infer certain aspects of the runoff hydrographs of the north slope basins by reference to basins of the monadnock type for which discharge records are available. As well, the range of hypsometric curves among the Babbage sub-basins - contrast, for example, the Crow River and Deep Creek (Figure 6) - may impart characteristics to the lower Babbage River hydrograph which are different from those of the lower Blow River whose sub-basins have nearly identical hypsometric curves (Figure 5).

Because snowmelt is such an important component of the total Yukon coast runoff, the distribution of area with elevation plays an important role in determining the form of a river's runoff hydrograph. A basin such as the Crow can be expected to have a flatter post-breakup flood wave than Deep Creek because so much of the latter basin lies within a narrow elevation range (Figure 6) and maximum rates of snowmelt will occur in all parts of the basin at the same time. Generally, because of the "monadnock" form of most of the larger north slope basins, post-breakup floods can be expected to be relatively severe.

## Hydrology and hydrograph estimation

Because of the scarcity of systematic data, the hydrologic characteristics of Yukon north slope basins can only be inferred from a combination of physical principles and the scattered data that are available. The major yearly flow events are a snowmelt-induced spring flood and surges following summer rainstorms. By late fall (October), surface flow declines to a very low level or, on most of the rivers, ceases altogether. Some groundwater flow will continue in many locations. According to a local resident (pers. comm. Bob Mackenzie), no rivers of the Yukon coastal plain continue to flow throughout their length during the winter but unfrozen pockets have been observed on both the Firth and Malcolm rivers.

Only one year of systematically collected discharge record is available from the entire Yukon coastal plain, that from the Firth River gauging station installed by the Water Survey of Canada in the spring of

Table II. Drainage Basin Characteristics.

| River | Tributary | Field Study Reach | River Location: Specific Site | North Latitude | West Longitude | Elevation (m. ASL) | Distance From River Mouth (km.) | Drainage Basin Area (km.²) | Basin Area Above Study Reach (km.²) | Per Cent Total Basin Area | Maximum Elevation in Basin (m.) | Basin Circularity Rc | Hypsometric Integral HI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Craig Creek | | | Mouth, Clarence Lagoon, Beaufort Sea | 69°37' | 140°54' | 0 | 0 | 120 | | | 930 | 0.441 | |
| Unnamed "A" | | | Mouth, Clarence Lagoon, Beaufort Sea | 69°38' | 140°51' | 0 | 0 | 170 | | | 1100 | 0.319 | |
| Backhouse River | | | Mouth, Beaufort Sea | 69°36' | 140°32' | 0 | 0 | 86 | | | 590 | 0.674 | |
| Fish Creek | | | Mouth, Beaufort Sea | 69°36' | 140°08' | 0 | 0 | 240 | | | 960 | 0.425 | |
| Malcolm River | | | Mouth, Beaufort Sea | 69°34' | 139°36' | 0 | 0 | 1100 | | | 2000 | 0.281 | |
| | | M1 | | 69°27' | 139°59' | 130 | 21 | | 930 | 89 | | | |
| Firth River | | | Mouth, Beaufort Sea | 69°33' | 139°29' | 0 | 0 | 6200 | | | 1800 | 0.273 | |
| | | F1 | | 69°28' | 139°30' | 22 | 10 | | 6000 | 97 | | | |
| | | F2 | | 69°22' | 139°32' | 86 | 24 | | 5700 | 92 | | | |
| | | (WSC)[1] | | 69°20' | 139°34' | 98 | 28 | | 5700 | 92 | | | |
| Unnamed "B" | | | Mouth, Roland Bay, Beaufort Sea | 69°22' | 138°56' | 0 | 0 | 270 | | | 590 | 0.538 | |
| Spring River | | | Mouth, Beaufort Sea | 69°17' | 138°37' | 0 | 0 | 560 | | | 1400 | 0.439 | |
| | Roland Creek | | Roland-Spring Junction | 69°15' | 138°52' | 26 | 23 | 190 | | 34 | 1200 | 0.462 | |
| | Spring above Roland | | Roland-Spring Junction | 69°15' | 138°52' | 26 | 23 | 290 | | 51 | 1400 | 0.403 | |
| Unnamed "C" | | | Mouth, Phillips Bay, Beaufort Sea | 69°14' | 138°36' | 0 | 0 | 230 | | | 590 | 0.543 | |
| Babbage River | | | Mouth, Phillips Bay, Beaufort Sea | 69°14' | 138°27' | 0 | 0 | 5000 | | | 1500 | 0.414 | 0.262 |
| | | B1 | | 69°09' | 138°20' | 8.5 | 16 | | 4200 | 85 | | | |
| | | B2 | | 69°04' | 138°17' | 19 | 36 | | 2400 | 48 | | | |
| | | B3 | | 69°00' | 138°09' | 32 | 59 | | 2300 | 47 | | | |
| | | B4 | | 68°58' | 138°25' | 52 | 81 | | 1800 | 36 | | | |
| | | B5 | | 68°54' | 138°35' | 73 | 96 | | 1700 | 34 | | | |
| | Crow River | | Crow-Babbage Junction | 69°08' | 138°22' | 11 | 21 | 970 | | 19 | 1500 | 0.355 | 0.398 |
| | Trail River | | Trail-Babbage Junction | 69°07' | 138°22' | 12 | 22 | 770 | | 15 | 1200 | 0.265 | 0.393 |
| | Deep Creek | | Deep-Babbage Junction[2] | 69°13' | 138°23' | 2.5 | 5.0 | 700 | | 14 | 530 | 0.261 | 0.206 |
| | Babbage above Trail | | Trail-Babbage Junction | 69°07' | 138°22' | 12 | 22 | 2500 | | 50 | 1100 | 0.342 | 0.303 |
| Running River | | | Mouth, Mackenzie Bay, Beaufort Sea | 68°57' | 137°16' | 0 | 0 | 420 | | | 900 | 0.340 | |
| | | RU1 | | 68°51' | 137°31' | 58 | 25 | | 230 | 54 | | | |
| | Tundra Creek | | Tundra-Running Junction | 68°52' | 137°31' | 41 | 17 | 110 | | 27 | 430 | 0.379 | |
| | Running above Tundra | | Tundra-Running Junction | 68°52' | 137°31' | 41 | 17 | 250 | | 58 | 910 | 0.353 | |
| Blow River | | | Mouth, Mackenzie Bay, Beaufort Sea | 68°57' | 137°06' | 0 | 0 | 3700 | | | 1500 | 0.420 | 0.284 |
| | | BL1 | | 68°53' | 137°04' | 10 | 10 | | 3700 | 98 | | | |
| | | BL2 | | 68°47' | 137°15' | 27 | 26 | | 2500 | 67 | | | |
| | | BL3 | | 68°41' | 137°31' | 74 | 47 | | 1600 | 43 | | | |
| | | BL4 | | 68°36' | 137°38' | 100 | 61 | | 1300 | 34 | | | |
| | | BL5 | | 68°33' | 137°48' | 130 | 72 | | 990 | 27 | | | |
| | Rapid Creek | | Rapid-Blow Junction | 68°50' | 137°06' | 17 | 16 | 1100 | | 28 | 1400 | 0.335 | 0.295 |
| | | R1 | | 68°40' | 136°49' | 100 | 32[3] | | 690 | 65[4] | | | |
| | Blow above Rapid | | Rapid-Blow Junction | 68°50' | 137°06' | 17 | 16 | 2500 | | 67 | 1500 | 0.365 | 0.289 |
| Eagle Creek | | | Edge of Mackenzie Delta | 68°46' | 136°35' | - | 0 | 240 | | | 660 | 0.552 | |
| Big Fish River | | | Edge of Mackenzie Delta | 68°38' | 136°07' | - | 0 | 2300 | | | 1700 | 0.463 | |
| | | BF1 | | 68°38' | 136°08' | - | 1.0 | | 2300 | 100 | | | |
| | Little Fish River | | Little Fish-Big Fish Junction | 68°33' | 136°16' | 52 | 15 | 1300 | | 59 | 1700 | 0.414 | |
| | Big Fish above Little Fish | | Little Fish-Big Fish Junction | 68°33' | 136°16' | 52 | 15 | 840 | | 37 | 1400 | 0.471 | |

[1] Water Survey of Canada Gauging Station.

[2] There are three Deep Babbage junctions; the most downstream one is used here.

[3] From Rapid-Blow junction.

[4] Of total Rapid area.

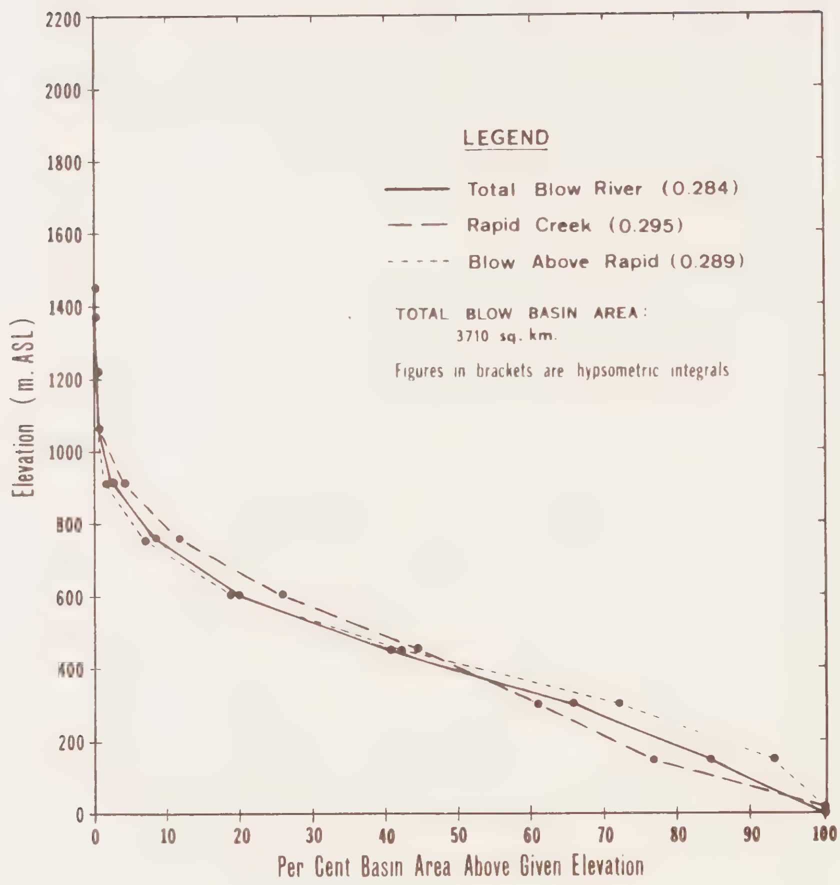



Figure 5. Hypsometric curves: Blow River basin.

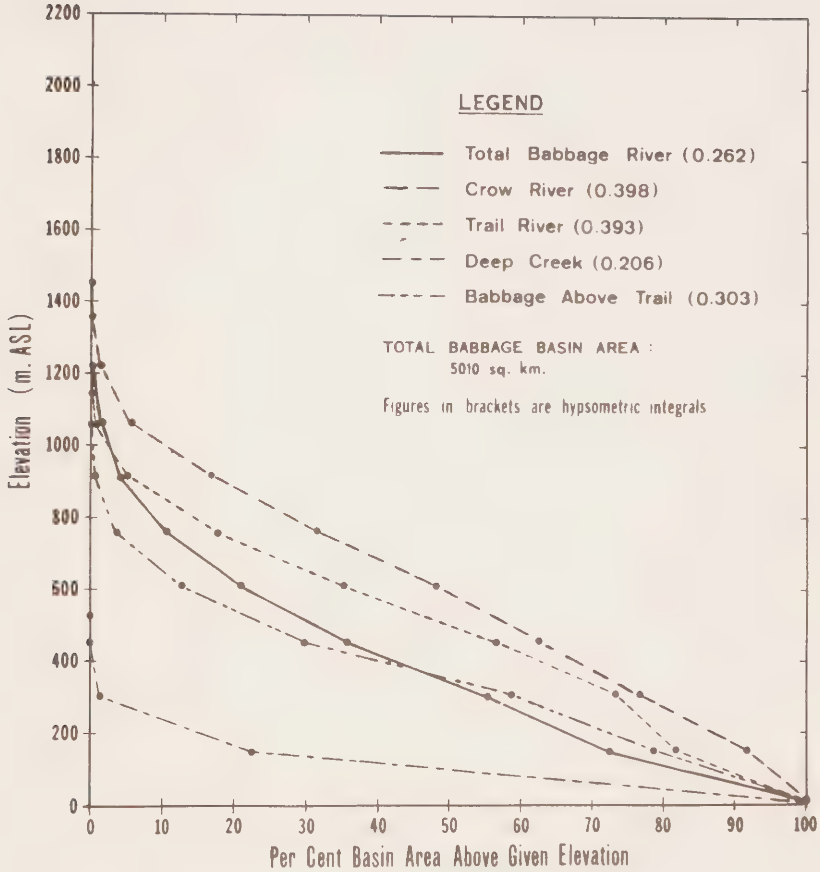



Figure 6. Hypsometric curves: Babbage River basin.

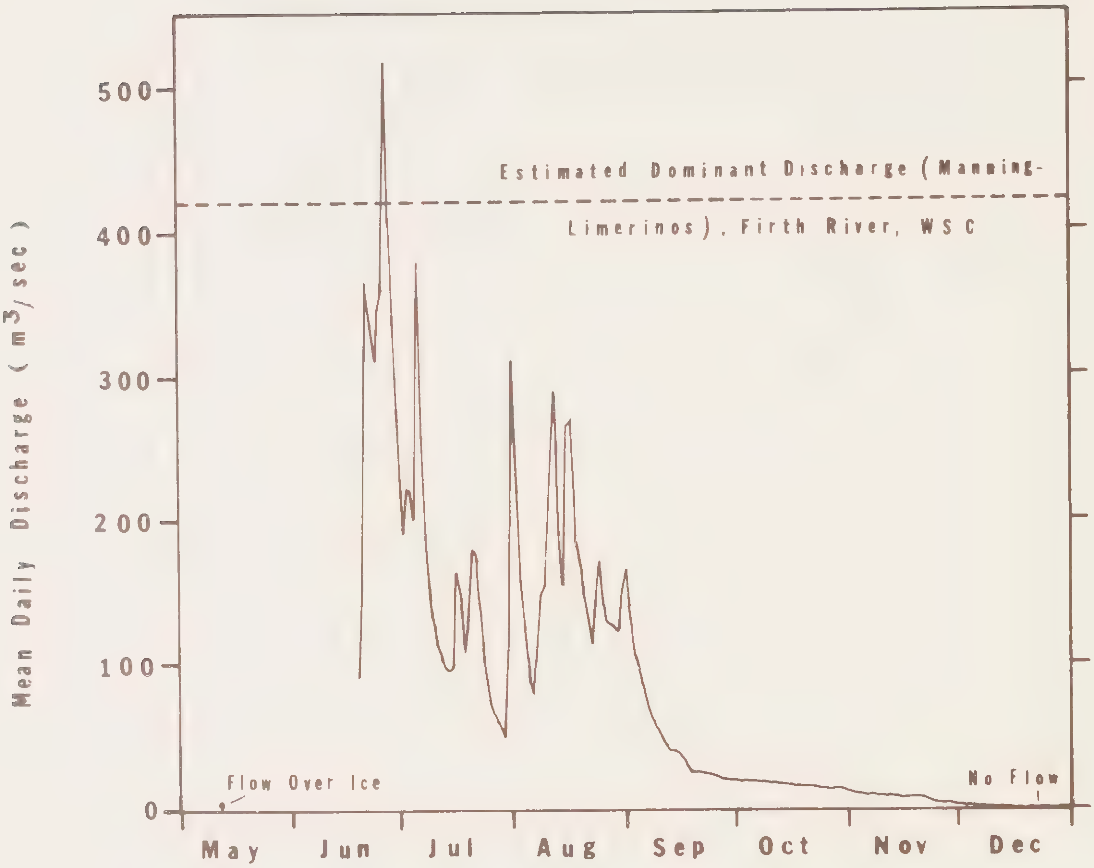



Figure 7. Discharge hydrograph, 20 June - 31 December, 1972 for reach F (WSC).
(Data courtesy of Water Management, Department of Environment)

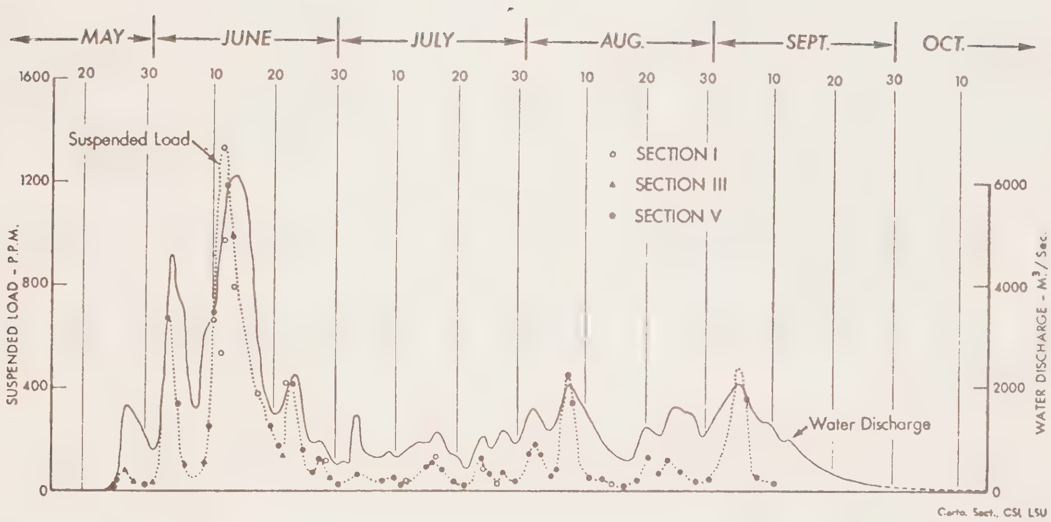



Figure 8. Suspended load and discharge, Colville River, Alaska, 1962.
(from Arnborg, Walker, and Peippo, 1967)

1972 (Figure7; river reach F(WSC) in Appendix). Flow began over river ice in May. The snowmelt-induced spring flood may have occurred in late June but this cannot be verified because of superimposed storm peaks and a large gap in the record. A number of storm surges were recorded in July and August. Flow decreased rapidly in September and had ceased by December.

Walker and Arnborg (1965) recognize five periods in the annual cycle of the Colville River on the Alaskan north slope. Yukon coast hydrographs are probably similar in form. The hydrograph for the 1962 flow season of the Colville is given in Figure 8. The longest period, river frozen, begins in October with freeze-up and lasts until break-up in May. Flow continues beneath the ice for some time but eventually the ice reaches the bottom and surface flow in the channel ceases.

In May rising air temperatures begin to melt the accumulated snow. Initial flow is on top of the winter ice cover. On the Colville in 1962, this flow reached 3 m. in depth before the bottom-fast ice began to surface (Walker and Arnborg, 1965). This pre-breakup phase is followed by break-up. Surprisingly little ice jamming was noted by Arnborg, Walker and Peippo (1966) during break-up on the Colville in 1962 or by McCloy (1970) on the Blow River in 1967. This was attributed to two factors: first, that the ice had formed at low water stage and thus covered only a small portion of the flood channel width; and, second, that the major ice movement occurred during rising stage so jams were floated free.

The break-up period lasts only several days and may be followed by a post-break-up flood or floods which are conditioned by peak snowmelt rather than by ice jamming. In 1967 the highest flood stage on the Blow River was not reached until approximately three weeks after break-up (McCloy, 1970). The length of this delay was probably anomalous because of unusual weather conditions but it illustrates well the two distinct flood types.

Summer flow is established by mid-June. The general discharge trend is downward as the snow cover is removed but occasional summer storms can cause rapid rises in river stage. McCloy (1970) discusses the effect of one such storm on the Blow River in July 1967. Figure 9 shows the hydrograph of a storm surge on the Babbage River in June-July, 1972. Photographs of study reach B2 (Map No. 1) at two stages of the surge are presented in Figures 10 and 11. Rain began on 25 June and continued through 29 June. Floods of this type can be major and may even exceed the post-break-up flood in magnitude (Church, 1971).

Measurements of study reach F2 (Map No. 1) on the Firth River on 17 July 1972 coincided with a small storm surge (Figure 7). Both the Firth and Babbage river measurements illustrate the dramatic increase of suspended sediment concentration during such periods of increased discharge (Table VIII).

Another feature of the earlier part of the summer period is a mild diurnal periodicity in water levels, due undoubtedly to diurnal variations in snowmelt. This was noted by McCloy (1970) on the Blow River and by the writers on the Babbage River in June 1972. The effect diminishes as the runoff contribution of direct snowmelt decreases in later summer.

One of the major differences between arctic and temperate drainage basins is the presence in the former of an impermeable layer of frozen ground. This acts as a barrier to infiltration and to groundwater flow. Surface runoff in the arctic, therefore, is usually by far the most important component of total runoff. In areas of high relief, frozen ground will aid rapid surface runoff thus accentuating peak flows during

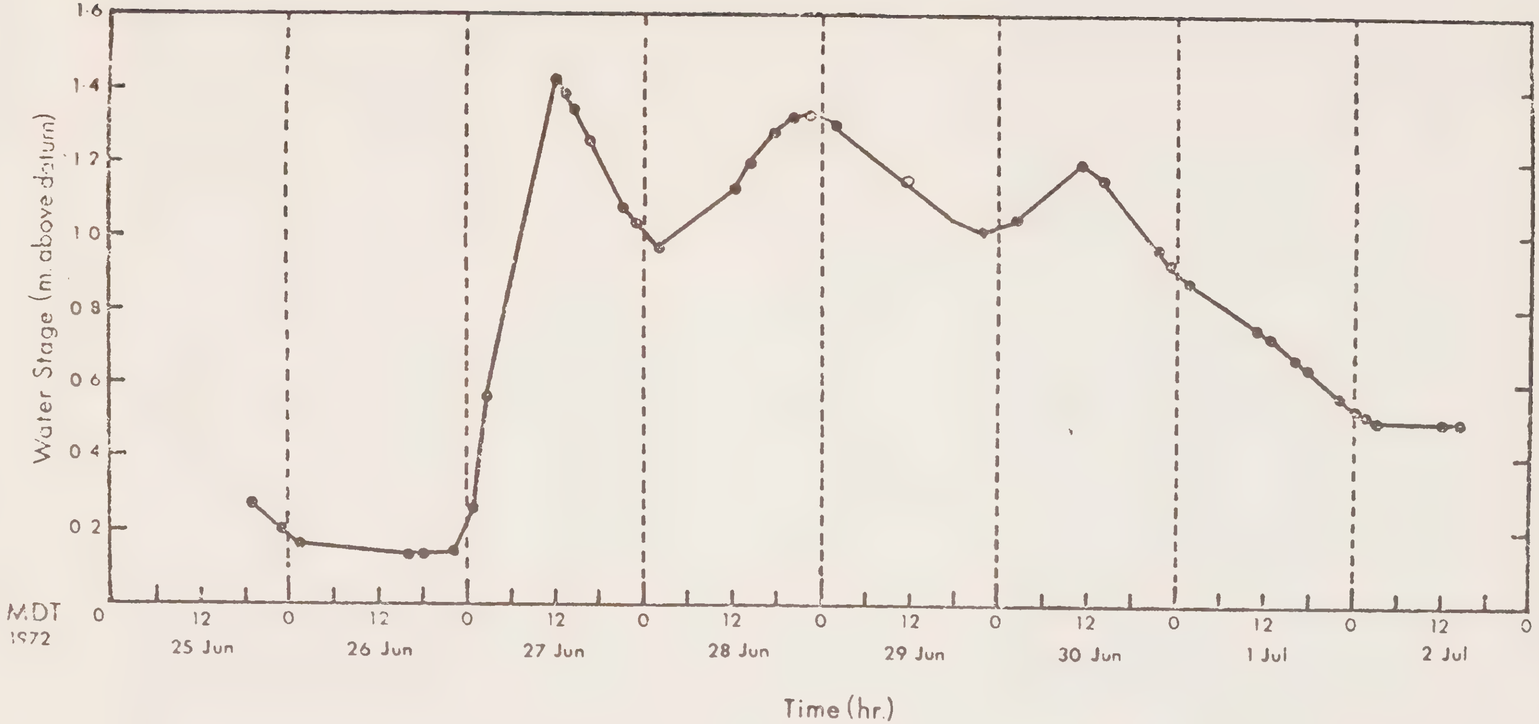



Figure 9. Summer storm surge on the Babbage River at reach B2, 25 June - 1 July, 1972.

Figure 10. Babbage River, reach B2; view downstream at high stage.
(1210 MDT, 27 June 1972; GSC 202261 - K)

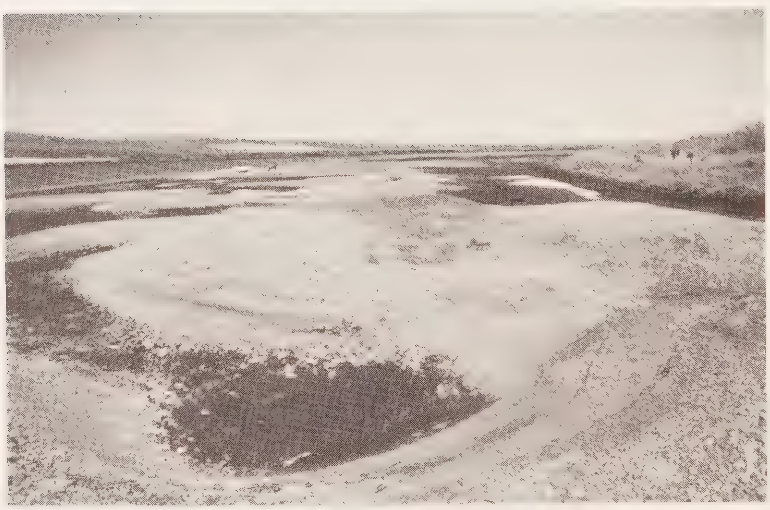


Figure 11. Babbage River, reach B2; view downstream at low stage.
(1320 MDT, 2 July 1972; GSC 202261)

runoff events. In places of low relief, however, frozen ground may have a quite different effect. Channel development will be hindered by the frozen substrate and by associated minor relief features such as tundra polygons. Standing water will be common in bogs and meadows. Some drainage may occur but it will be slow because of the high resistance and damming ability presented by the vegetation. This, in turn, will result in attenuation of flow event hydrographs by delaying drainage to the main channels (cf. Dingman, 1966).

Beneath even small rivers in the arctic, unfrozen zones (taliks) may persist late into or even through the winter. Groundwater flow will continue in these zones. If advancing seasonal frost reaches the permafrost table at some point, the resultant pressure caused by the blocked flow may enable it to break through the seasonal frost and form an aufeis (icing, naled) on the surface. These may persist through the summer if sufficiently large. Aufeis is present in the lower areas of the Firth (Figure 12) and Malcolm rivers, and Fish Creek. If the flow does not break through to the surface, the pressure may simply bulge the ground upward, thereby forming an open-system pingo. Such a pingo was observed on the alluvial fan of the lower Malcolm River. Aufeis or open-system pingos could constitute an obtruction to the resumption of surface flow in the spring. Construction practices which would tend to facilitate their development should, therefore, be avoided.

Flood-frequency predictions based on the rational equation of Church (1971) and on the grid-square method were introduced in Section 5.1.1. The "maximum probable flood" estimated by the rational equation should be roughly comparable to the flood with a 50-year recurrence interval estimated by the grid-square method. The predictions for Yukon north slope rivers according to these two methods are shown in Table III along with dominant discharges calculated from field data (see Section 6.1.4.). Grid-square estimation of mean values of hydrologic parameters for the Yukon coastal plain is hampered by the scarcity of nearby systematic hydrologic data. This has resulted in the extension of measured data controls across major physiographic boundaries into the coastal plain where mountains to the south and the Beaufort Sea to the north exert a considerable influence on the hydrologic regimen.

Several points of comparison could be noted from the estimates in Table III.

(a) In all cases except one, discharges measured in the field (usually at low stage; see Appendix) are less than the estimated mean of annual discharge maxima. However, a discharge of 183 $m^3$./sec. was measured during the summer storm surge at reach B2 on the Babbage River. This measured discharge exceeds even the 50-year flood predicted by the modified grid-square method. Since this storm surge did not even completely inundate the active, unvegetated part of the river bed, the grid-square prediction seems to be unreasonably low;

(b) In most cases the dominant, channel-forming, or bankfull discharge calculated from field measurements exceeded the 50-year flood predicted by the grid-square method. Because the dominant discharge can be expected to have a recurrence interval of less than one year and because it is likely that north slope dominant discharges have been under-estimated (see Section 6.1.4). the grid-square predictions are almost

Figure 12. Aufeis on Firth River fan; note sediment that is melting out from the ice. (17 July 1972; GSC 202262-0)

Table III. Discharge Estimates for Rivers of Yukon North Slope.

| Drainage basin (See map no. 1 for locations) | Basin area above mouth or designated study reach ($Km^2$) | Rational Equation | | Modified Grid-Square Method | | Manning-Limerinos dominant discharge[3] ($m^3$/sec) | Discharge measured in field ($m^3$/sec) |
|---|---|---|---|---|---|---|---|
| | | Coefficient | Q[1] ($m^3$/sec) | Mean of annual Q maxima ($m^3$/sec) | $Q_{50\text{-year}}$[2] ($m^3$/sec) | | |
| Craig Creek | 120 | 0.63 | 65 | 7 | 11 | | |
| Unnamed "A" | 170 | 0.57 | 84 | 9 | 15 | | |
| Backhouse River | 86 | 0.70 | 52 | 4 | 7 | | |
| Fish Creek | 240 | 0.51 | 110 | 12 | 20 | | |
| Malcolm River | 1100 | 0.32 | 310 | 47 | 81 | | |
| M1 | 930 | 0.34 | 270 | 43 | 73 | 300 | 12 |
| Firth River | 6200 | 0.19 | 1000 | 223 | 386 | | |
| F1 | 6000 | 0.19 | 990 | 217 | 375 | 340 | 58 |
| F2 | 5700 | 0.20 | 990 | 213 | 368 | 420 | 197 |
| F(WSC) | 5700 | 0.20 | 990 | 213 | 368 | | |
| Unnamed "B" | 270 | 0.49 | 110 | 12 | 21 | | |
| Spring River | 560 | 0.40 | 190 | 26 | 45 | | |
| Roland Creek | 190 | 0.55 | 91 | 9 | 16 | | |
| Spring R. above Roland C. | 290 | 0.48 | 120 | 14 | 24 | | |
| Unnamed "C" | 230 | 0.52 | 110 | 10 | 18 | | |
| Babbage River | 5000 | 0.21 | 910 | 186 | 321 | | |
| B1 | 4200 | 0.22 | 800 | 163 | 282 | 330 | 62 |
| B2 | 2400 | 0.26 | 540 | 97 | 167 | 500 | 73;183 |
| B3 | 2300 | 0.26 | 520 | 94 | 163 | 110 | 39 |
| B4 | 1800 | 0.28 | 440 | 74 | 127 | 160 | 42 |
| B5 | 1700 | 0.28 | 410 | 69 | 119 | 320 | 38 |
| Crow River | 970 | 0.34 | 290 | 42 | 73 | | |
| Trail River | 770 | 0.36 | 240 | 36 | 62 | | |
| Deep Creek | 700 | 0.37 | 220 | 27 | 46 | | |
| Babbage R. above Trail R. | 2500 | 0.25 | 540 | 98 | 170 | | |
| Running River | 420 | 0.43 | 160 | 23 | 40 | | |
| RU1 | 230 | 0.52 | 100 | 11 | 19 | 140 | 0.4 |
| Tundra Creek | 110 | 0.65 | 62 | 6 | 10 | | |
| Running R. above Tundra C. | 250 | 0.51 | 111 | 12 | 21 | | |
| Blow River | 3700 | 0.22 | 710 | 144 | 248 | | |
| BL1 | 3700 | 0.22 | 710 | 142 | 245 | 410 | 33 |
| BL2 | 2500 | 0.25 | 540 | 107 | 185 | 260 | 23 |
| BL3 | 1600 | 0.29 | 400 | 68 | 117 | 140 | 7.0 |
| BL4 | 1300 | 0.31 | 350 | 55 | 94 | 150 | 4.3 |
| BL5 | 990 | 0.33 | 280 | 42 | 73 | 150 | 3.0 |
| Rapid Creek | 1100 | 0.32 | 310 | 37 | 64 | | |
| R1 | 690 | 0.37 | 220 | 22 | 38 | 93 | 3.8 |
| Blow R. above Rapid C. | 2500 | 0.25 | 540 | 108 | 187 | | |
| Eagle Creek | 240 | 0.51 | 110 | 12 | 20 | | |
| Big Fish River | 2300 | 0.26 | 520 | 93 | 161 | | |
| BF1 | 2300 | 0.26 | 520 | 93 | 161 | 160 | 7.7 |
| Little Fish River | 1300 | 0.31 | 350 | 57 | 98 | | |
| Big Fish above Little Fish | 840 | 0.35 | 260 | 36 | 63 | | |

[1] Based on rational formula of Chow (1964): "Maximum probable flood" or peak discharge (Q) = CiA

[2] Discharge with a 50-year recurrence interval

[3] Dominant, or channel-forming, discharge calculated from field data using the Manning-Limerinos uniform flow formula (see text).

Table IV

Valley and Channel Characteristics, Yukon North Slope

| Morphology \ Headwaters | British Mountains | Porcupine Plateau | Richardson Mountains |
|---|---|---|---|
| Valley Characteristics | | | |
| (a) Form | Deep, steep-walled valleys; alluvial fans extend across Coastal Plain from mountain front | Gentle side slopes; valley depth decreases markedly toward coast | Steep to vertical bed-rock valley walls |
| (b) Terraces | Two to three levels | One to two low levels on the outer part of the Coastal Plain | Multiple unpaired remnants |
| Channel Characteristics | Braided to wandering | Meandering to wandering | Wandering |
| Examples | Firth River, Malcolm River (See Figure 15) | Babbage River, Running River (See Figure 16) | Blow River, Big Fish River (See Figure 17) |

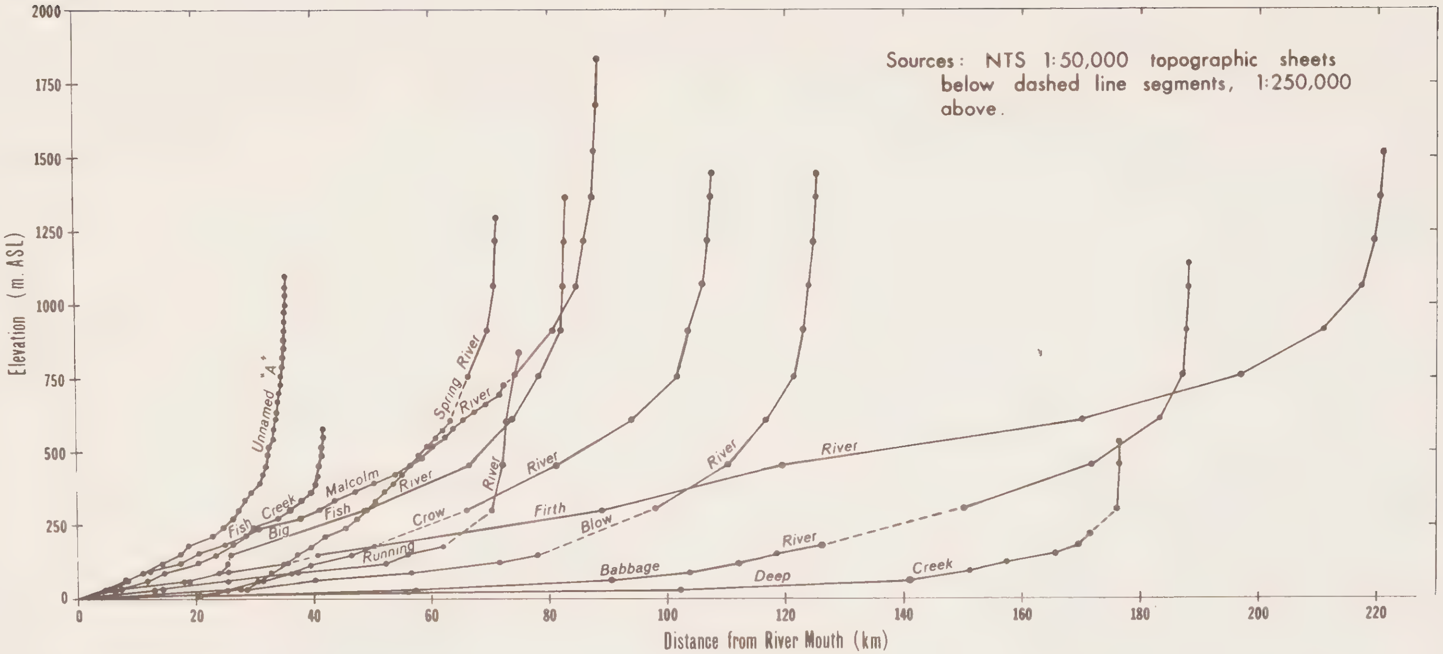



Figure 13. River long profiles, Yukon north slope.

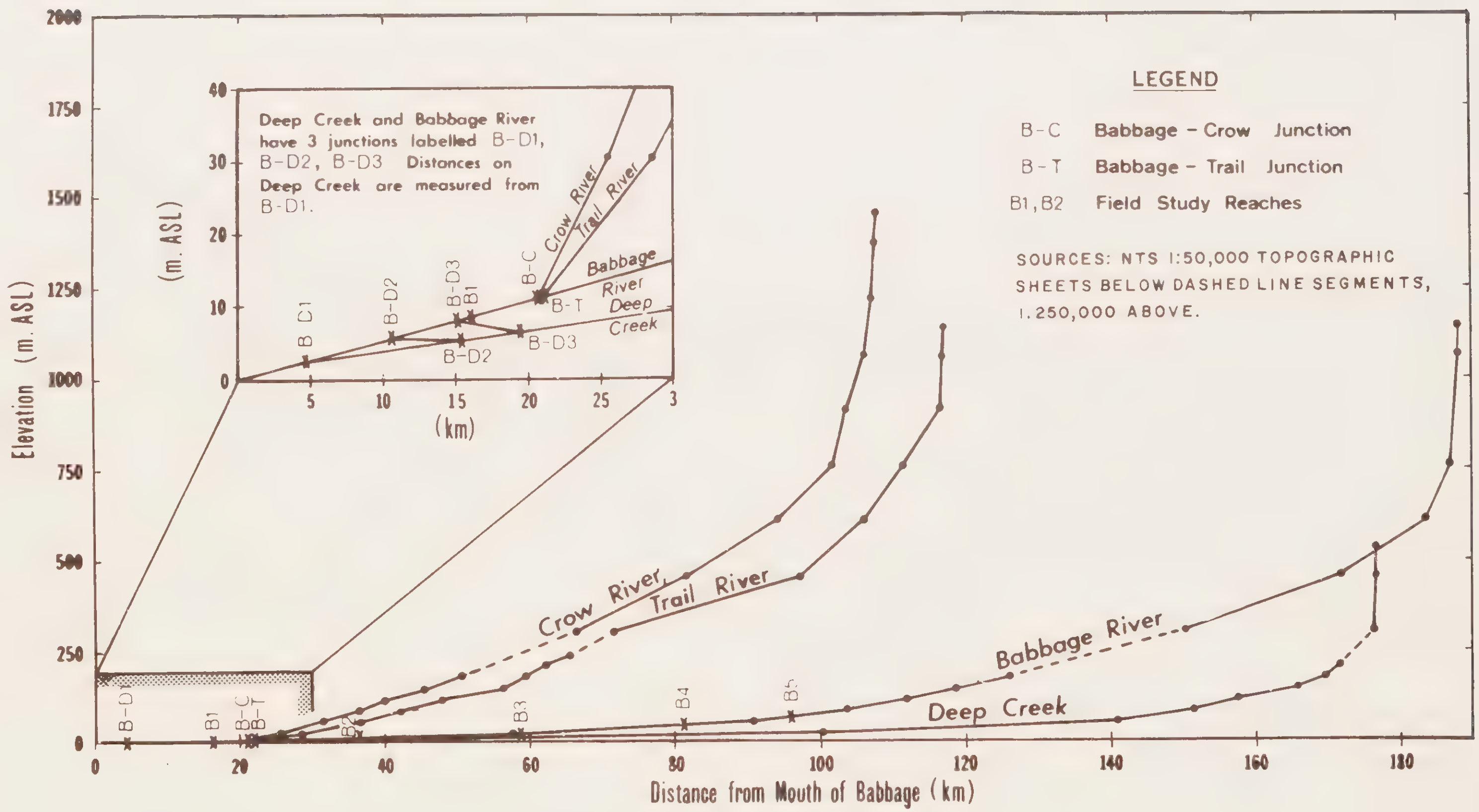



Figure 14. River long profiles, Babbage River basin.

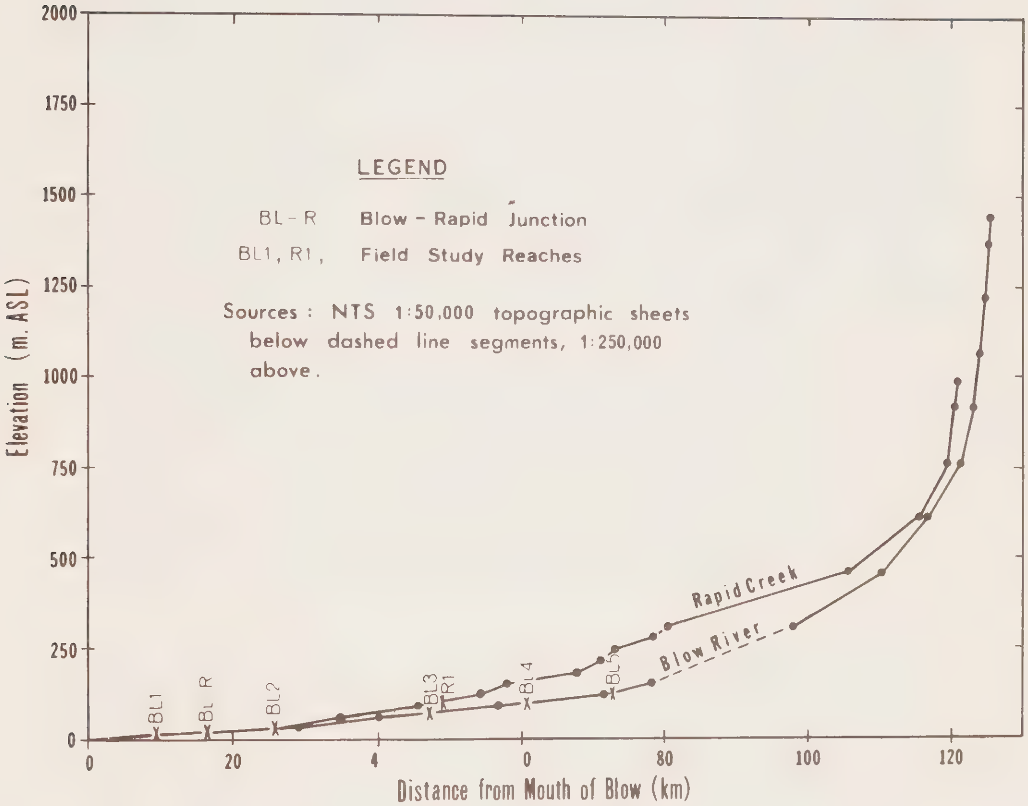



Figure 15. River long profiles, Blow River basin.

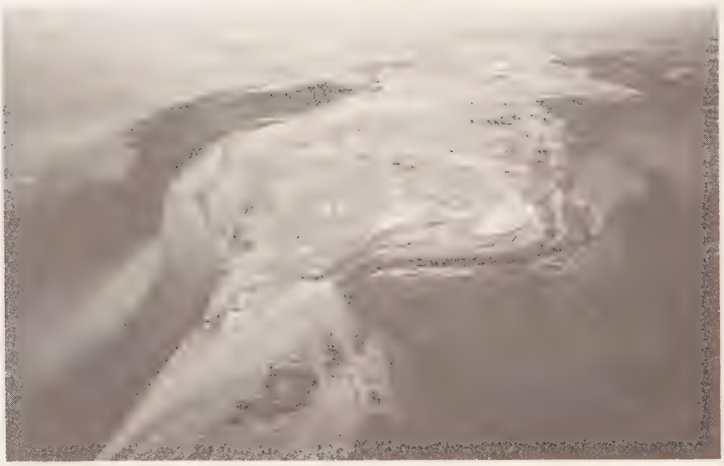


Figure 16. (Top). Braided channel of Malcolm River, looking downstream; reach M1 in middle distance. (13 July 1972; GSC 202262 - M)

Figure 17. (Middle). Meandering channel of Running River, looking downstream reach RU1 in foreground. (30 July 1972; GSC 202262 - Y)

Figure 18. (Bottom). Wandering channel of Blow River, looking upstream; reach BL2 in middle distance. (26 July 1972; GSC 202261 -C)

Figure 19. Trail River incised in bedrock, looking upstream from point about 13 km. upstream from Babbage River. (15 June 1972; GSC 202262 - S)

Figure 20. Braided portion of Crow River, looking upstream from point about 8 km. upstream from Babbage River. (15 June 1972; GSC 202262 - X)

certainly too low.

(c) The 50-year flood predicted by grid square is consistently 3 to 6 times lower than the maximum probable flood predicted by the rational equation.

It would appear that the maximum probable floods, which are in most cases 1 to 3 times larger than the dominant, or bankfull, discharges calculated from field data, more reasonably approximate a suitable design flood than do floods predicted by the grid-square method.

### 6.1.2. River Valley and Long Profiles

Valley and channel characteristics vary with physiography and are summarized in Table IV according to whether the rivers rise in the British Mountains, the Porcupine Plateau, or the Richardson Mountains.

All rivers are incised below the coastal plain surface to some extent (see, for example, Figures 18 and 19). On the valley bottoms low vegetated terraces flank the active unvegetated surface. Local slope failures on valley walls of unconsolidated material with high ice content may supply a significant amount of sediment to the lower reaches of the Porcupine Plateau rivers.

Long profiles of some of the Yukon north slope rivers are presented in Figures 13,14, and 15. For the most part these profiles are concave upward. This form may be attributed to a number of factors, the most important of which are increase in discharge and decrease in size of bed material in a downstream direction. Both of these trends impart to a river the ability to carry a given sediment load at a reduced gradient.

The general upward concavity is interrupted on many of the profiles, however, by a pronounced break of slope, usually near the mountain front between 100 and 200 m. ASL. See, for example, the plots for Unnamed "A", the Malcolm River and the Spring River on Figure 13, Trail River on Figure 14, and Rapid Creek on Figure 15. Lack of large scale map coverage may have prevented recognition of these breaks of slope on several of the other rivers.

A possible cause of these profile irregularities is that a decrease in the sediment load supplied to the rivers has increased their competence to erode their beds. This would result in degradation, particularly where the channel bed is alluvial or only weakly consolidated (the shales of the Lower Blow River). The required initial decrease in sediment load is somewhat difficult to account for, though. Commonly the rate of sediment supply can be said to have been pushed up to very high levels because of the plentiful debris left by retreating glaciers. As this material is used up, the supply rate falls to that which can be supplied by weathering. The upper part of the Yukon coast basins and those basins in the Yukon west of the Firth River were not glacierized during the Quaternary, however. In any case, the continued braided habit of large portions of the rivers suggests that any over-competence has not endured for sufficient time to account for all of the 25 to 50 m. of downcutting by rivers such as the Blow.

A second possibility is tectonic activity. Most of the rivers appear to be incised to at least some extent in both their lower mountain and coastal plain segments.

The advance of a knickpoint upstream would result in a break of slope in the river's long profile.

Widespread entrenchment of valleys, unpaired terrace levels, and

knick points in long profiles are indications of long-term degradation. Certainly the change in channel pattern from braided to wandering which has occurred on some rivers and the occurrences of bedrock in channel bottoms suggest that aggradation is not taking place on a regional scale. On the other hand, in most places on the coastal plain, rivers flow in their own alluvium. On reaches BL1 and BL2 of the lower Blow River (Map No.1), for example, seismic refraction data suggest an alluvial fill of 30 to 40 m. thickness.

It is possible that the following sequence of events has controlled valley morphology:

(a) moderate preglacial incision into a pediment surface in response to tectonic uplift or late Tertiary drop in sea level,

(b) accelerated incision to lowered base levels as sea level fell during the Quaternary glacial maxima,

(c) alluvial infilling of valleys accompanying late-glacial rise of sea level, and,

(d) slow present-day degradation in response to tectonic uplift or to a decrease in sediment supply.

It is important to note, though, that the rates of channel degradation are geologic in scale and thus are unlikely to affect a pipeline during its short project lifetime. It would not be wise, however, to choose the location of a knickpoint in weak bed material as a river crossing site.

### 6.1.3. Channel Pattern and Channel Form

Channel patterns of north slope rivers range from full meandering to braided (see classification presented in Table I). In the western narrower end of the coastal plain, gradients and sediment transport rates are high resulting in braided channels (Table IV; Figures 16 and 20). These change to meandering and wandering channels in areas draining the Porcupine Plateau (Figure 17) and to wandering channels in the southeastern portion of the coastal plain (Figure 18). Many channel reaches have one bedrock bank, due to incision below the pediment surface (Figures 18 and 19).

Most Yukon north slope rivers have been actively aggrading braided streams at some point in the past. The large alluvial fans of the Firth and Malcolm rivers, extensive areas of which are now inactive and incised, are the best evidence of this. Today, some channels on the coastal plain remain braided. Many of the rivers now have a dominant low water channel, however, and might be called "wandering" (Mollard, 1973).

Although wandering channels are most prominent, meandering segments are not uncommon. The coastal plain section of Deep Creek is perhaps the most extreme illustration. Figure B4:5A (see Appendix) shows a fully developed meandering portion of the Babbage River. Most of the Yukon north slope rivers seem to lie very close to the braided-meandering boundary in their coastal plain sections, a situation that makes their hydraulic characteristics difficult to predict because they fall between regime types.

Braiding in situations like that of the north slope rivers is most commonly caused by an over-supply of sediment. Meandering channels, on the other hand, are the reaction of initially underloaded streams. The sinuosity increases form resistance and reduces specific energy

expenditure by lenghening the channel course (Church, 1972). The recent tendency, then, in the Yukon rivers has probably been toward underloaded streams, particularly in the southeastern half of the coastal plain. This in turn, has resulted from decreased supply of debris and/or an increased number of flow events of sufficient magnitude to move bed material.

### 6.1.4. River Hydraulics and Discharge Estimation

Dominant discharge (see Section 5.1.4.), particularly if a recurrence interval can be assigned to it , is a useful indicator of the sediment movement characteristics of a river system. The concept is not well developed for gravel rivers, however, and its definition is far from objective.

Velocities predicted by each of three uniform-flow formulas were compared with velocities measured in the field to see which would give the most reliable estimates of dominant discharge. The formulas and the mean per cent errors for their estimates of 15 measured velocities on north slope rivers are given in Table V. The Limerinos (1970) method of computing the roughness coefficient n leads to substantially better estimates of mean velocity by the Manning formula than do relationships of the Strickler or Irmay type (Lane and Carlson, 1953). Kellerhals (1967) equation was tested because it is based on data from gravel rivers.

Although the Manning - Limerinos method gives the best results, it over-estimates by almost 30 per cent. The cause of this lack of agreement is not immediately apparent. Given random errors in R and S, errors in n could be caused by under-estimates of grain size parameters or by the presence of significant form roughness.

Dominant discharge estimates for the Yukon north slope study reaches based on the Manning-Limerinos method are given in Table VI. The estimates are low in comparison to those based on Carlston's (1965) meander wavelength equation (assuming bankfull discharge $Q_b$ to be dominant). Threshold grain sizes based on Neill's (1967) criterion are generally much smaller than measured $D_{84}$ sizes (Table VI). This also suggests that dominant discharges have been under-estimated.

The high low-flow and probably low dominant discharge values may indicate that the Manning equation fails to adequately describe these gravel rivers. Church (1972), with much more complete hydraulic geometry data, found this to be the case for his Baffin Island streams. The definition of bankfull stage used or lack of equivalence between bankfull and dominant conditions may also have contributed to the under-estimates of dominant discharge.

### 6.1.5. Sediment Transport

#### Bedload

The braided to wandering pattern and gravel beds of many of the coastal plain river channels indicate that much, if not most, of the sediment in them is moved as bedload. As was mentioned in Section 5.1.5, no measurements of transport rates are available. Painted lines across coarse gravel bars did indicate, however, that substantial movement of gravel took place on at least several study reaches between the summers of 1972 and 1973. Data for reaches Firth F2 and Blow BL5, the two most extreme examples, are given in Table VII.

Table V

Reliability of Velocity Estimates, Yukon North Slope Rivers

| Formula | Mean Per Cent Error | Standard Deviation Per Cent Error |
|---|---|---|
| Manning Formula: | +28.8 | 49.9 |
| $V_m = \frac{1}{n} R^{2/3} S^{1/2}$ (metric units) | | |
| where $n = \frac{0.113 R^{1/6}}{1.16 + 2.0 \log (\frac{R}{D_{84}})}$ | | |
| after Limerinos (1970) | | |
| Logarithmic Formula: | +62.1 | 59.6 |
| $V_m = V_* [6.0 + 5.75 \log (\frac{R}{D_{90}})]$ | | |
| where $V_* = \sqrt{gRS}$ | | |
| after Kellerhals (1967) | | |
| Kellerhals (1967) Formula: | +63.7 | 58.4 |
| $V_m = V_* [6.5 (\frac{\bar{d}}{D_{90}})^{1/4}]$ | | |

Table VI

Dominant Discharge Computations

| River | Study Reach | Contributing Basin Area (km.$^2$) | Maximum Elevation in Basin (m.) | Manning-Limerinos Dominant Discharge (m.$^3$/sec.) | Carlston Dominant Discharge (m.$^3$/sec.) | Neill's Threshold Grain-size (m.) | Measured $D_{84}$(m.) |
|---|---|---|---|---|---|---|---|
| Malcolm River | | 1100 | 2000 | | | | |
| | 1 | 930 | | 300 | | 0.044 | 0.079 |
| Firth River | | 6200 | 1800 | | | | |
| | 2 | 6000 | | 340 | | 0.035 | 0.079 |
| | 3 | 5700 | | 420 | | 0.10 | 0.074 |
| Babbage River | | 5000 | 1500 | | | | |
| | 4 | 4200 | | 330 | | 0.011 | 0.052 |
| | 5 | 2400 | | 500 | 680 | 0.022 | 0.039 |
| | 6 | 2300 | | 110 | | 0.0087 | 0.084 |
| | 7 | 1800 | | 160 | 530 | 0.013 | 0.042 |
| | 8 | 1700 | | 320 | | 0.044 | 0.084 |
| Running River | | 420 | 900 | | | | |
| | 9 | 230 | | 140 | 260 | 0.049 | 0.050 |
| Blow River | | 3700 | 1500 | | | | |
| | 10 | 3700 | | 410 | | 0.024 | 0.056 |
| | 11 | 2500 | | 260 | | 0.027 | 0.060 |
| | 12 | 1600 | | 140 | | 0.019 | 0.084 |
| | 13 | 1300 | | 150 | | 0.029 | 0.14 |
| | 14 | 990 | | 150 | | 0.056 | 0.19 |
| Rapid Creek | | 1100 | 1400 | | | | |
| | 15 | 690 | | 93 | | 0.030 | 0.084 |
| Big Fish River | | 2300 | 1700 | | | | |
| | 16 | 2300 | | 160 | | 0.029 | 0.091 |

Table VII

Movement of Painted Gravel

| Study Reach: | F2 | BL5 |
|---|---|---|
| number of painted grains measured | 48 | 13 |
| maximum downstream movement (m.) | 18.0 | 24.3 |
| mean downstream movement (m.) | 3.4 | 15.2 |
| maximum D moved (m.) | 0.166 | 0.216 |
| mean D moved (m.) | 0.064 | 0.129 |

The removal of these painted lines and the size of material moved suggest that flows capable of transporting significant amounts of bed and bar material are not uncommon on Yukon north slope rivers.

Suspended and dissolved load

Few data are available on the movement of suspended and dissolved load. McCloy (1970) gives values ranging from 20 to 3390 mg./l. for spot samples from the Blow River delta, with the high value being taken at the crest of a July storm flood. Data on suspended load concentrations collec-ed by the writers ranged from 0 to 4823 mg./l. and for suspended plus dissolved load from 73 to 4957 mg./l. (see Appendix). Again the high values were associated with summer storm floads. Table VIII illustrates the effect of a storm flood on sediment concentrations at reach B2. Reach F2 was visited during a storm surge and sediment concentrations observed are also presented in Table VIII.

Suspended load concentrations for the Colville River in 1962 are illustrated in Figure 8. The increase in concentration during storm floods is apparent. Generally, sediment concentration is positively correlated with discharge but peak concentration precedes peak discharge. This is normal on most rivers and occurs because of initial easy availability of sediment left as lag deposits from the previous hydrologic year and perhaps also loosened during spring and fall frost cycles. On the Colville, three fourths of the annual total of suspended load was moved during the 20 days centered on break-up (Arnborg, Walker and Peippo, 1967) but this proportion could fall significantly during a year of frequent storm floods.

6.1.6. Channel Stability

The stability of north slope rivers at a geologic time scale was discussed in Section 6.1.2. Of more relevance to construction activities are changes which occur at a seasonal or even a storm event scale. In these cases, erosion and deposition may result in an oscillation of channel configuration about an equilibrium position. This oscillation, in itself, may be of sufficient magnitude to damage or destroy improperly placed structures. Also, the structures, themselves, may affect both the oscillation and the equilibrium position.

Bed scour

Many of the factors influencing the intensity and distribution of bed scour were listed in Section 5.1.6. The principal scour events occur during high discharge and scour depressions can be largely filled in again during

Table VIII

Suspended and Dissolved Sediment Loads[1]

| Study Reach | B2 Low Water | B2 Storm Surge | F2 Storm Surge |
|---|---|---|---|
| Date of Observation | 1 Jul 72 | 27 Jun 72 | 17 Jul 72 |
| Q ($m.^3/sec.$) | 73.1 | 183 | 197 |
| $C_s$ (mg./1.) | 59 | 2225 | 4820 |
| $C_s + C_c$ (mg./1.) | 103 | 2331 | 4957 |
| $Q_s$ (kg./sec.) | 7.53 | 427 | 977 |
| Sediment Load Grain-size Statistics: | | | |
| Per Cent Sand (> 62.5 $\mu$) | - | 71.5 | 3.0 |
| Per Cent Silt ( 1.95-62.5 $\mu$) | - | 17.6 | 85.5 |
| Per Cent Clay (< 1.95 $\mu$) | - | 10.9 | 11.2 |
| $D_m$ (mm.) | - | 0.077 | 0.013 |

1 Analyses courtesy of Water Management, Department of Environment.

falling stage. Consequently, the importance of bed scour at a given reach may be difficult to assess during a field visit at low stage. Field evidence of bed scour was observed, however, and scour chains and painted gravel lines have provided some information on channel bar stability.

The flood boundaries of gravel channels commonly assume a condition referred to by Church (1972) as "underloose". The bed surface is imbricated and, as a result, offers more resistance to scour than would be expected merely on the basis of material size. Most river sections on the Yukon coastal plain have gravel beds and display this imbrication. These lag pavements are probably stable under most flow conditions.

Permafrost will have some effect on bed stability. It is likely that the sediments beneath large portions of the coastal plain channels are permanently frozen. The situation is probably similar to that found by Brewer (1958) for the Shaviovik River in northern Alaska - frozen ground but considerable modification to the thermal regime. The heat from flowing water will maintain an unfrozen layer next to the channel during most of the runoff season so resistance of the bed to normal scour is likely to be little affected. In the early spring, though, flow may take place over the winter ice cover. Scour of bed sediment cannot take place in these circumstances and, even where the ice cover is removed, rates of scour may be inhibited for at least a short period of time by the presence of frozen ground.

In spite of both imbrication and near surface frozen ground, considerable bedload movement will take place during floods. Loose material stored on top of the imbricated pavement is more susceptible to erosion than is the pavement itself. For many flood discharges lateral cutting into gravel bars may be the most important method of material supply. Scour chains on bar tops were largely undisturbed between the summers of 1972 and 1973 but considerable erosion occurred on bar sides. In several instances, painted gravel lines were truncated by lateral erosion but no movement of sediment occurred on the bar tops.

At many reaches localized scour of a particular type was observed to have taken place on even the highest bar surfaces. Gravel had been "bulldozed" into small ridges (Figure 21) that together outlined small angular areas. Stones in the centers of these areas had a flat, paved appearance. These scour features are ascribed to the gounding of floating ice pans as river stage fell after the spring break-up flood.

Scour depressions result also from macro-eddies caused by channel configuration. At reach B1 on the Babbage River flow divides into two channels around a large vegetated island (Figure B1:1 in Appendix). Scour depressions (Figure 22) immediately upstream of this island are as deep as 1.3 m. Their depth may be partly controlled by the nearness of the frost table.

Lateral cutting of channel banks and localized erosion on bar surfaces then, may be the most common forms of bed scour in Yukon coastal plain rivers. Church (1972), as well, has found that in gravel-bed rivers an increase in discharge is taken up largely by increased velocity and increased width. Depth changes very little. During major flood events, however, the entire bed surface including the imbricated pavement will be in motion and channel bars may be completely removed and re-deposited in different locations.

Figure 21. Small ridge of gravel pushed up, probably by the grounding of a floating ice pan as stage fell after spring flood; Babbage River, reach B2; shovel is 0.5 m. long.
(30 June 1972; GSC 202262 - R)

Figure 22. Scour holes just upstream from large vegetated island; fine sediment lag in holes; Babbage River, reach B1.
(2 July 1972; GSC 202261 - H)

Lateral stability

The tendency of gravel rivers to accommodate increasing discharge by widening rather than deepening suggests that, in many reaches, the high-water banks of coastal plain rivers may be less stable than the channel beds. These banks are usually composed of relatively fine-grained floodplain sediments, often underlain by relic gravel bars (Figure BL3:5B in Appendix). The semi-cohesive floodplain material is particularly susceptible to thermal niching and block slumping. Melting of the segregated ice in these channel banks by spring and summer flow leads to undercutting (Figure 23). Niches as deep as 3 m. have been measured at reach B5 on the Babbage River. As the active layer in these undercut banks thickens during the summer, blocks begin to fail and slump into the river where they are washed away (Figure 24). Such erosion is an important process by which the channels shift.

Stakes were placed along the channel bank at reach B5 in order to obtain data on the rate of erosion. The changes which occurred between 15 June and 25 July 1972 and between 25 July 1972 and 22 July 1973 are detailed on Figure 25C. Erosion of over 2 m. of the bank (almost the depth of the thermal niche) occurred in several locations during the summer of 1972. Between July 1972 and 1973 almost 6 m. of erosion occurred at one location on the bank. Average values of amount of retreat along a 50 m. length of bank were 0.8 m. between 25 July 1972 and 22 July 1973. During the 6-week period between measurements in the summer of 1972 the active layer thickened from about 0.5 m. to about 0.75 m. (Figure 25D).

On a larger scale, entire valley sides of ice-susceptible material may begin to slump when river attack strips enough vegetative cover to promote melting of ground ice. This process does not seem to be very common along the rivers of the Yukon coastal plain but several classic examples, both relic and active, exist on the Babbage River at study reach B2 (Figure B2:5B in Appendix). Ground-ice slumps can deliver appreciable volumes of sediment to a river system. The headwall of an active slump at B2 retreated over 10 m. between the summers of 1972 and 1973 (Figure 26).

Air photograph sequences (Figures 27,28,29 and 30) indicate that low-flow channel patterns on braided and wandering reaches are less stable than on meandering reaches. There is, however, no apparent correlation between channel type and rate of migration of the entire channel zone. In fact, few areas of rapid channel zone migration were evident in the air photographs.

Channels in braided reaches (Figure 27) are ephemeral and characteristically show significant relocation from year to year. The channel pattern of 1970 aerial photographs of the Firth River fan at study reach F1 bear little resemblance to the present pattern (Figure F1:1 in Appendix; see also Figure M1:1 in Appendix) indicating that bedload movement does occur. Vegetation and meander-scroll patterns at Babbage reach B5 (Figure 28) indicate that the channel shift there has been a progressive one and not a "catastrophic" change due to a particular discharge event. Meandering channels such as the lower Babbage show much less change of form (Figure 30). The shape and locations of many bars are substantially unchanged since the early 1950's. This does not preclude the possibility, however, that the bars have been removed and then re-established in the same position, or that the bars represent an equilibrium condition maintained by a bedload flux.

Figure 23. Thermal niche undercut into floodplain, causing collapse of bank; flow left to right, Babbage River, Reach B5.
(17 June 1972; GSC 202261 - F)

Figure 24. Slumped blocks due to thermally induced undercutting of river bank; flow toward camera; Babbage River, reach B5.
(17 June 1972; GSC; 202263 - B)

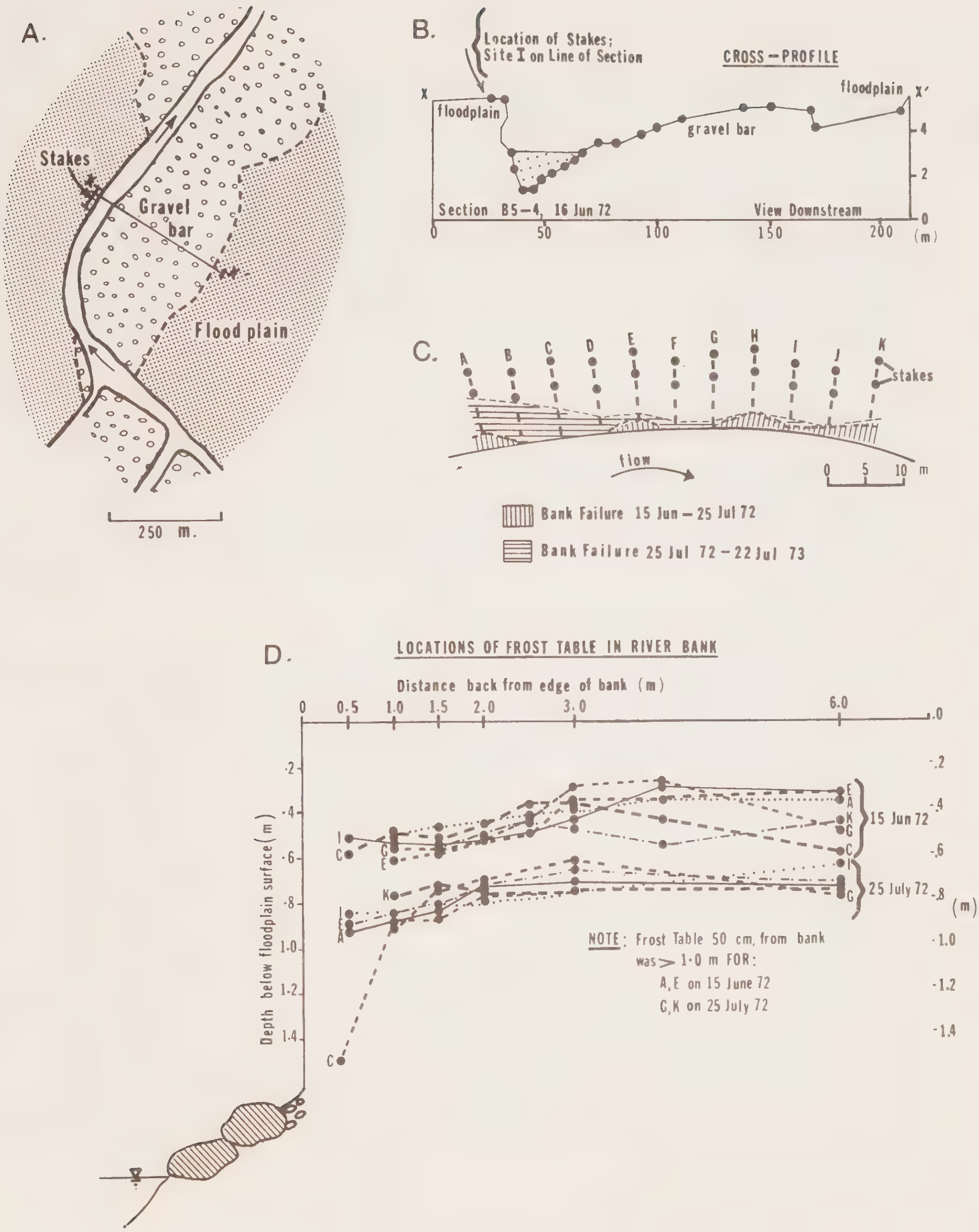



Figure 25. Details of river-bank erosion, Babbage River, reach B5.

A. Map of reach
B. Cross-profile; view downstream
C. Plan, showing bank failure
D. Cross-section of river bank showing lowering of frost table over a 6-week period.

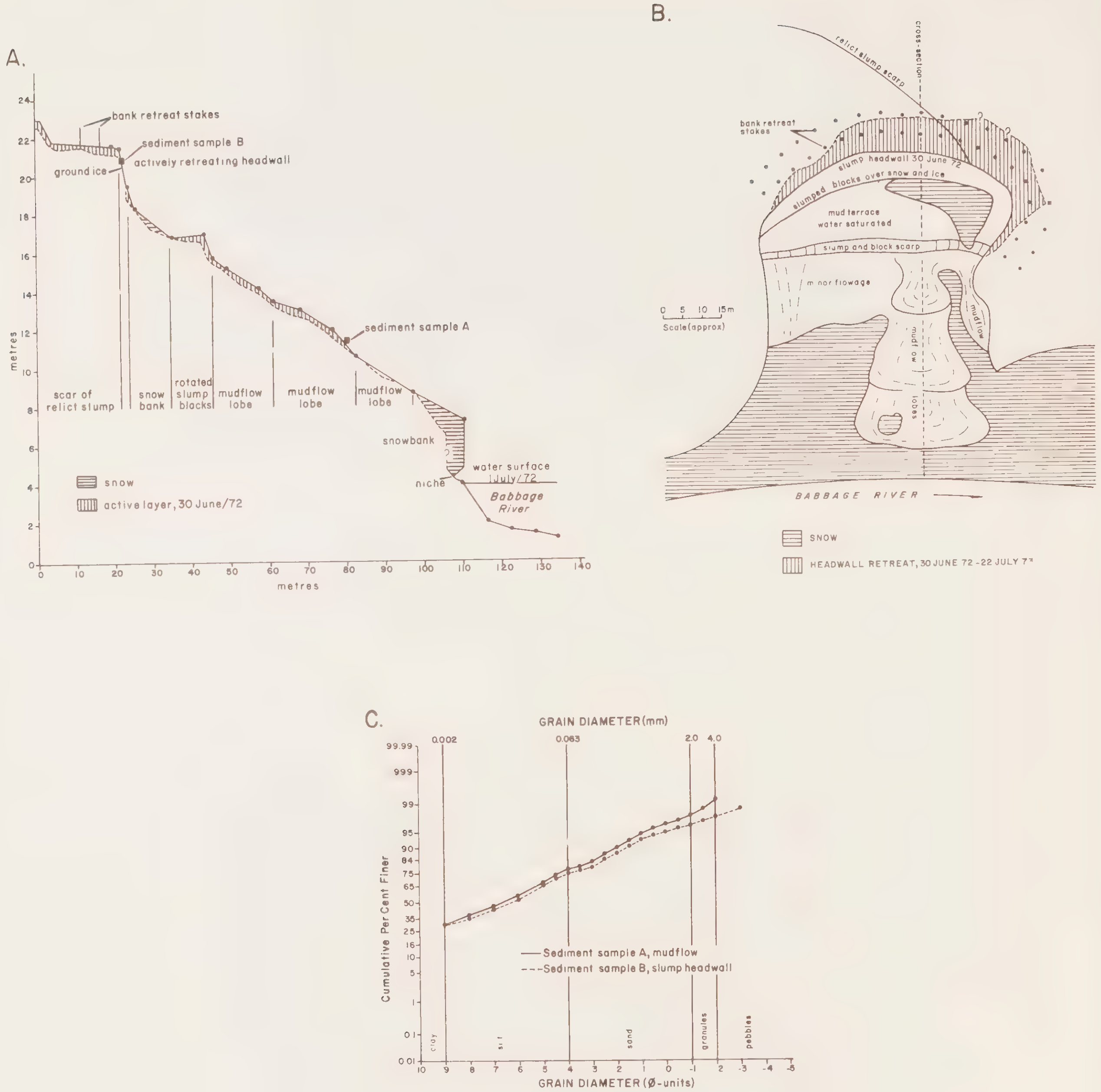



Figure 26. Ground-ice slump, Babbage River, reach B2.

A. Cross-section, 30 June 1972
B. Plan sketch, 30 June 1972
C. Grain-size distributions.

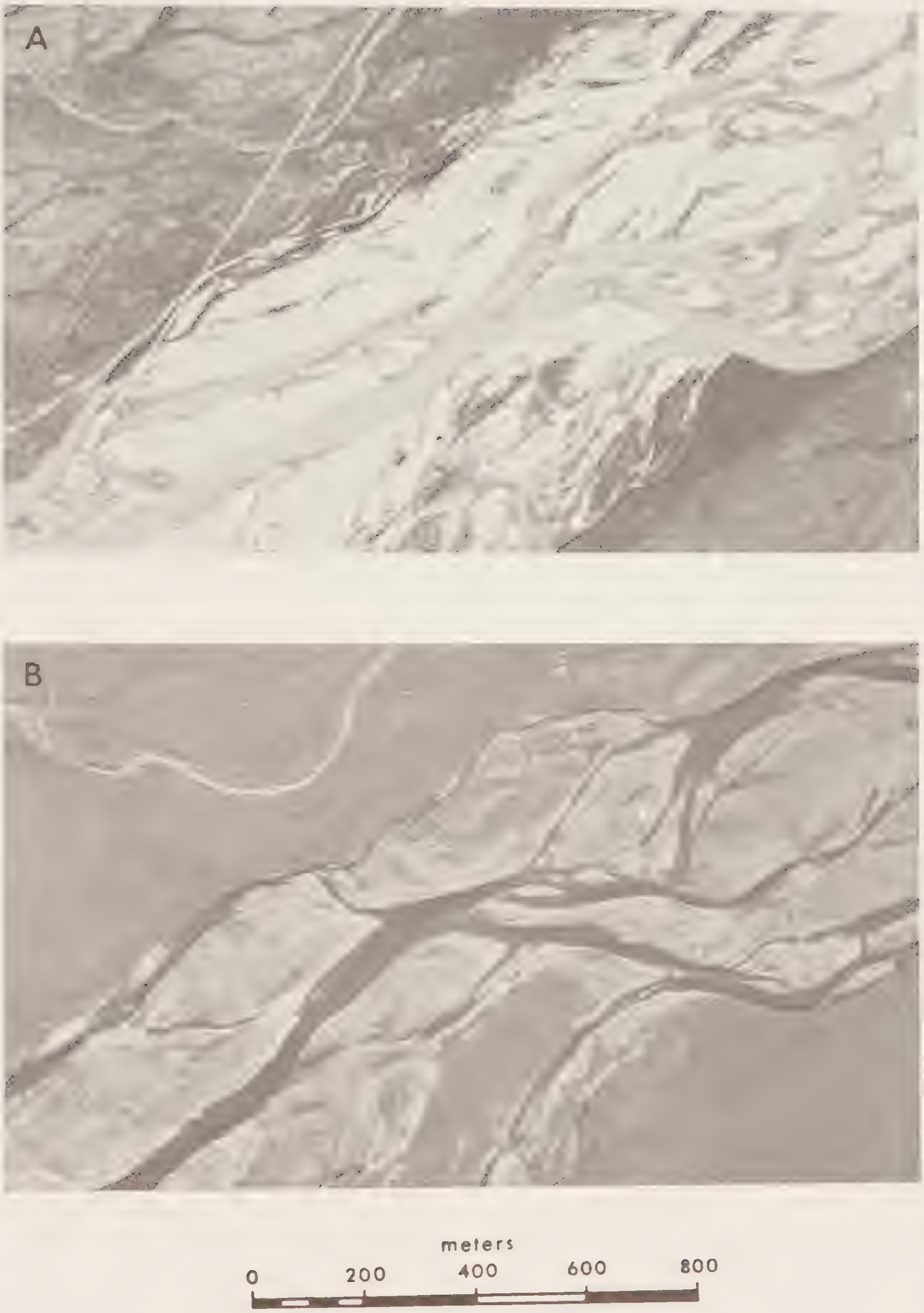



Figure 27. Evidence of channel shifting between 1952 and 1970 at braided reach F1, Firth River; flow from right to left.

A. 1952; air photo A13751-144
B. 1970; air photo A21925-88

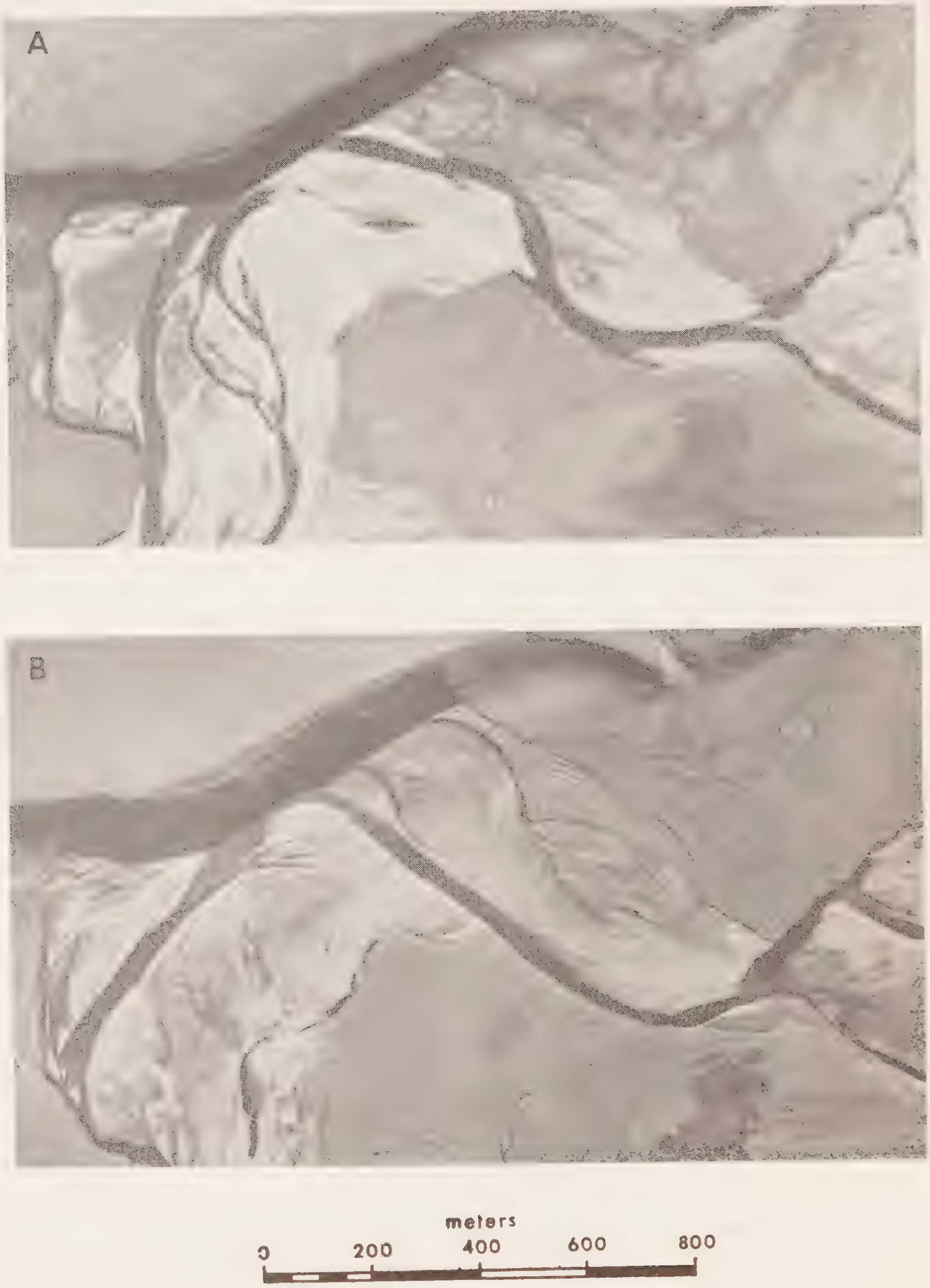



Figure 28. Evidence of channel shifting between 1952 and 1970 at reach B5, Babbage River; flow from right to left.

A. 1952; air photo A13382-144
B. 1970; air photo A21924-199

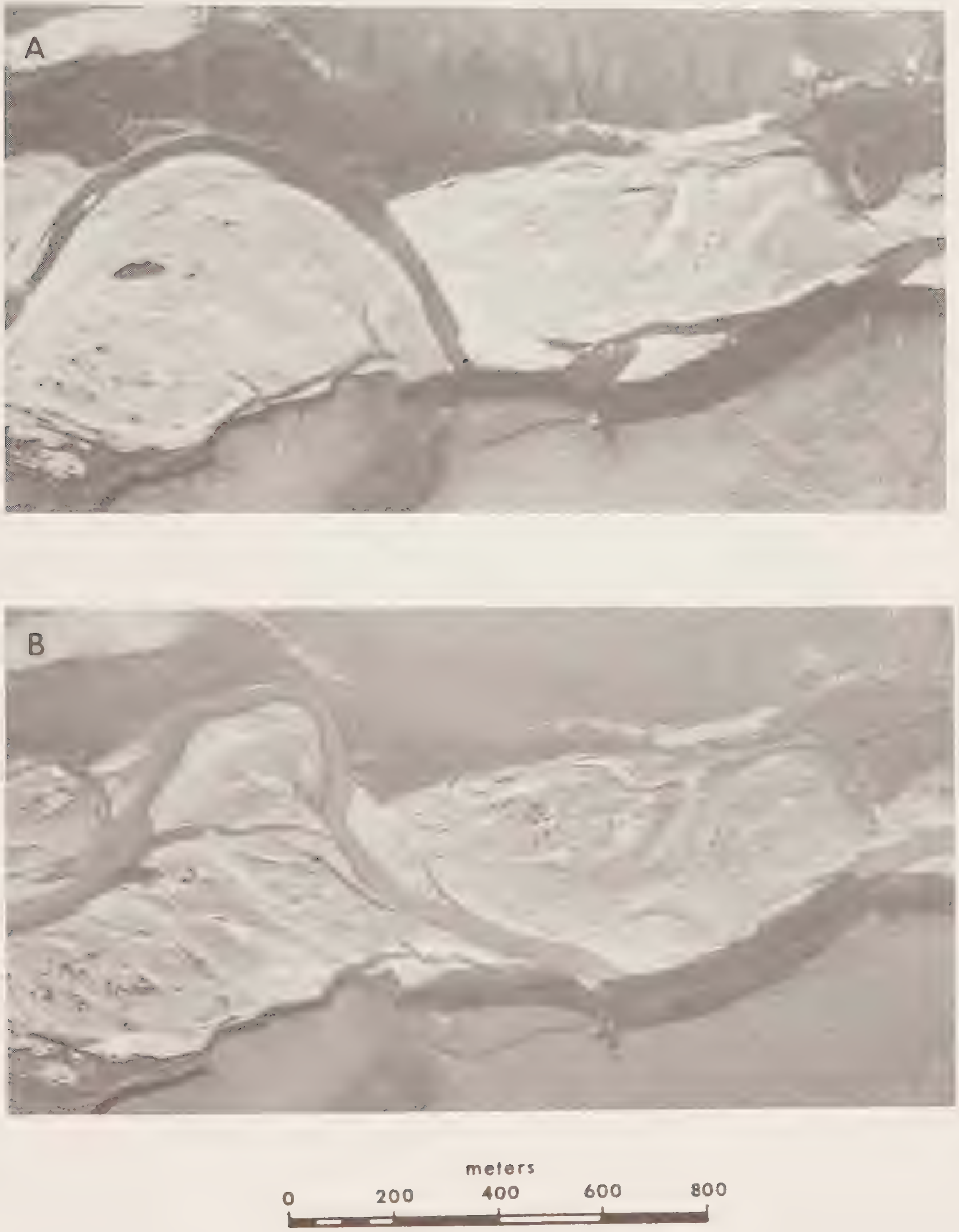



Figure 29. Evidence of channel shifting between 1954 and 1970 at wandering reach BL2, Blow River; flow from right to left.

A. 1954; air photo A14363-30
B. 1970; air photo A21922-91

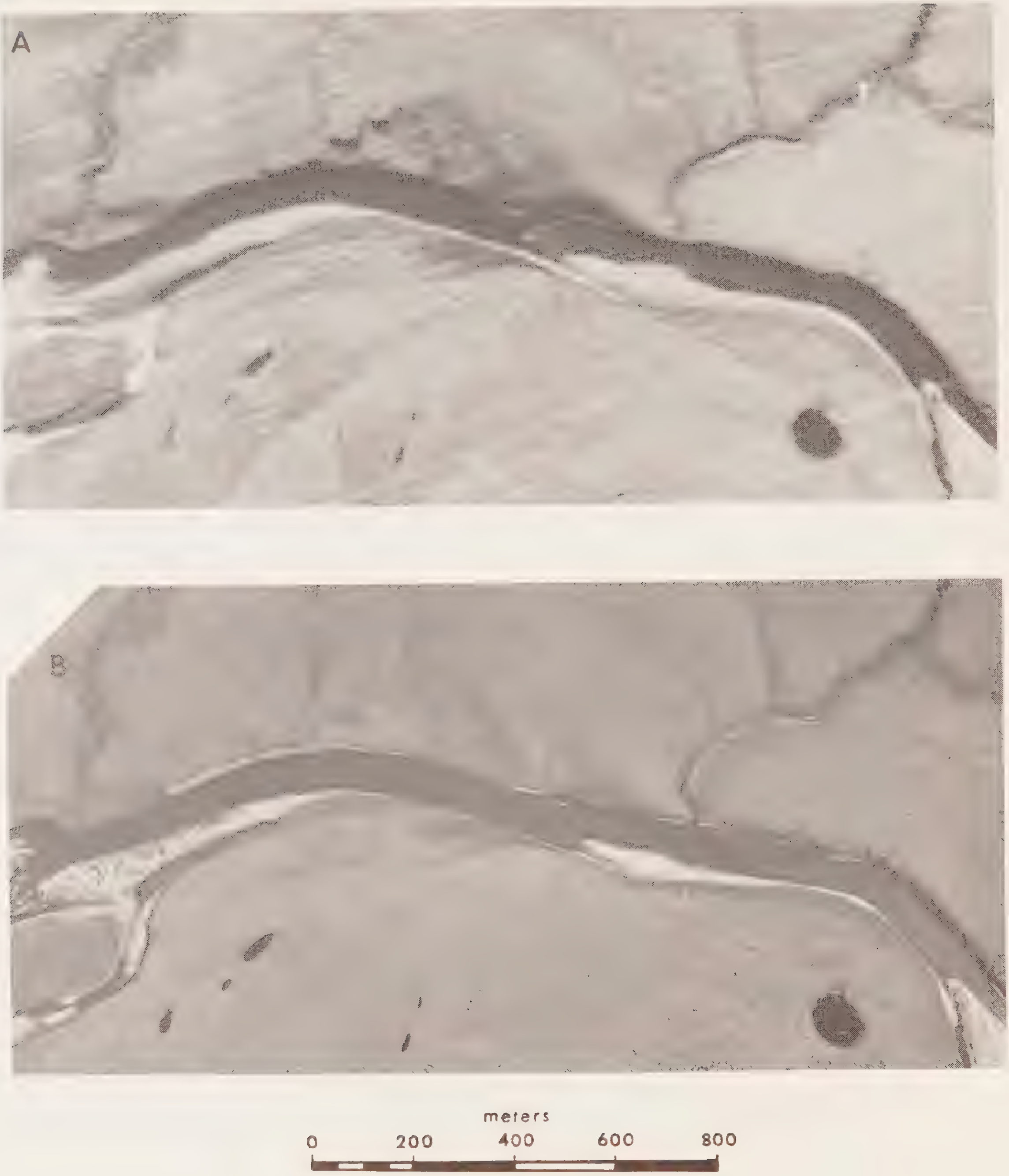



Figure 30. Channel at reach B3, Babbage River, has been stable since 1954, probably due to bedrock control; flow from right to left.

A. 1954; air photo A14406-44
B. 1970; air photo A21825-196

## 6.2. Coast

### 6.2.1. Sea-ice Conditions

General pattern during summer season

Sea-ice conditions between Alaska and the Mackenzie delta have been published by the Department of Transport since about 1953. Sea-ice conditions are shown on Map No. 2 for a particularly "bad" year - 1964, and for a particularly "good" year - 1968. The lines show the extent of 40% ice cover; the dates are on the iceward sides of the lines. Break-up comes first near the mouth of the Mackenzie River due to the discharge of relatively warm water from the spring floods of its more southern tributaries. Sea ice breaks up progressively westward along the Yukon coast as the summer progresses.

In 1964 a lead westward along the Alaskan coast did not open up until late August when edge of the ice pack lay about 100 km. offshore. By October 8 the coast NW of Kay Point was frozen in and by October 22 freeze-up was complete.

In 1968 break-up had extended to Kay Point by June 25 and by July 9 the whole coastal zone was ice-free. The edge of the ice pack lay several hundred kilometres offshore until sometime between October 8 and October 22 when new ice formed throughout the sea area shown on Map. No. 2.

The Yukon coastal zone experiences, therefore, between 3 and 4 months of ice-free conditions during which tens of kilometres of fetch are available for the generation of waves. Major storm surges can occur during this period. A storm in September, 1970 (estimated return period greater than 25 years) caused a surge which raised water levels an average of 2.4 m. above the astronomical tide of 0.76 m. (Department of Public Works, 1971).

Break-up

Throughout the winter and through much of spring break-up the coastal cliffs are protected from erosion (including eolian influences) by snow ramps extending commonly from sea level to the cliff top (Figure 31). This ramp is built by drifting snow during winter. Also, an ice-foot of shore-fast ice commonly last a few weeks past break-up and protects the shore zone from early surf action.

Rivers break-up and experience at least part of their spring flood before the coast is ice-free. The result is discharge of river water and sediment over bottom-fast sea ice near the river mouth. Where the sea ice is no longer supported by the bottom, i.e. at depths of about 2 m. the weight of river water contributes to cracking and break-up of sea ice. Over the next several days, bottom-fast ice floats to the surface in large pans, hundreds of metres in diameter, through the column of overlying river water. Sediment discharged during the spring flood is floated up on the ice. Water is transferred from above to below the ice pan through perforations in the pan (strudels). Vortices on the water surface mark these transfer points (Figure 32). This transfer may control the rate of flotation as the water below provides support for the ice pan. Circular scour holes probably develop on the bottom beneath these strudels. A probe 2.5 m. long failed to touch bottom through the vortex

Figure 31. Snow ramps protecting coastal cliffs near Sabine Point.
(10 June 1972; GSC 202262)

in Figure 32, yet echo sounding later in the season indicated water depths there of only 1.2 to 1.8 m.

Subsequent to general break-up, strong onshore winds are capable of driving ice floes up on shore. Ice push is potentially capable of exerting much stress on the shore but in 1972 its effects were minor. On Kay Point spit ice floes pushed ridges of gravel to about 2 m. above mean sea level (Figure 33) but even here normal processes of sediment transport in the shore zone had begun in a few days to repair the damage by reworking the sand and gravel and redepositing it in normal beach berms.

### 6.2.2. Coastal Erosion

#### Introduction

Where coastal cliffs are exposed to direct surf action they are eroded. The mechanics of this erosion can take several forms. Where the sediments are fine-grained, frozen, and contain masses of relatively pure ice within them direct surf action can effect pronounced erosion. Ground ice contained in the sediments, either in the form of pore ice or lenses of massive ice, melts rapidly and a thermo-erosional niche near sea level undermines the seaward edge of the cliff and culminates in collapse of the cliff face. Commonly, tundra polygons bounded by ice wedges occur at the ground surface. Melting of the wedges exposed at the cliff face results in short gullies that "flank" individual polygons. Then after a period of apparent coastal stability the whole polygon, measuring perhaps 30 m. across, tumbles into the shore zone. Ground-ice slumping, caused by melting of enclosed ice with subsequent loss of strength and failure of the slope, is a common failure type that lessens the slope of the coastal cliff, and transfers much sediment to the sea but doesn't directly result in coastal recession. In fact, the collapse of a large volume of sediment into the shore zone can result in a temporary displacement seaward of the shoreline. If ground ice is not prominent in the coastal cliffs, erosion can proceed in a particle by particle fashion under the influence of surf, surface runoff, and mass wasting processes.

When sediment from the coastal cliffs enters the sea, it is reworked in the shore zone. Coarser fractions (sand and gravel) are largely transported along the shore and stored in beaches, spit, bars, etc. These shore accumulations act temporarily to protect the coast behind them. Finner sediment (silt and clay) is transported in suspension to a more offshore location. The nature and rates of erosion which characterize specific portions of the Yukon coast are discussed below.

#### Alaska border to mouth of Firth River

On July 30, 1912, the International Boundary Commission established Monument No. 1 on the Alaska-Yukon border at the Beaufort Sea coast. Their original survey notebooks indicate that the monument was 61.9 m. from the top of the coastal cliff, 6.5 m. above sea level. On July 17, 1972, this monument was 18.9 m. from the top of the cliff (Figure 34). The net retreat in 60 years has been 43.0 m. Gullies have extended back from the cliff along ice wedges that border a polygon and they now flank the monument on two sides. Failure presently is by small debris flows down the cliff face, with only minor block slumping.

The low coastal cliff at the monument contains frozen pebbly silty clay and is characteristic (except for minor gravel elsewhere) of the

Figure 32. Strudel where water is being transferred to beneath the slowly rising ice pan; paddle for scale.
(12 June 1972; GSC 202261-P)

Figure 33. Ice-push features on Kay Point spit; Kay Point in background.
( 11 July 1972; GSC 202261 - L)

Figure 34. Monument on Yukon-Alaska border; gully in foreground is due to melting of an ice wedge.
(17 July 1972; GSC 202262 - C)

Figure 35. Mainland beach and coastal cliff between Clarence Lagoon and Komakuk Beach.
(17 July 1972; GSC 202262 - F)

roughly straight section of coast extending eastward to Komakuk Beach. At the monument, and at other locations between there and Komakuk Beach, the low cliffs in 1972 were temporarily protected by beaches less than 15 m. wide (Figure 35). Elsewhere in this zone, however, retreat of the coastal cliff was quite active (Figure 36).

The promontory on the coast at the mouth of Fish Creek may be partly a result of long-term retreat of as much as 700 m. of the coast west of Komakuk Beach during the time that Fish Creek has been delivering sediment to the sea at a rate sufficient to counteract locally the erosive effects of the sea.

Along much of this coast the flat ground surface near the top of the coastal cliffs is mantled with gravel and driftwood (Figure 37). This mantle is about 30 cm. thick at the cliff face and disappears 25 m. back from the cliff. Stones with intermediate axis 35 cm. long were observed in this mantle. Whether an exceptionally active surf, perhaps during a storm surge, was responsible for this deposit, or whether an active surf in combination with an ice ramp leading up to the top of the coastal cliff (as suggested by Duguid, 1971) might have been responsible, is unclear. Alternatively, ice alone may be responsible. J.J. O'Neill (1924), in his account of the 1913-18 Canadian Arctic Expedition, published a photograph taken at Camden Bay, Alaska, on 3 July 1914 showing sea ice shoved up over a low tundra shore and depositing boulders and driftwood trunks with very little disturbance of underlying material (O'Neill's Plate II).

From the mouth of Fish Creek at Komakuk Beach to Herschel Island the coast is characterized by sediment accumulation and the absence of prominent coastal cliffs.

## Herschel Island

The northeast, north and northwest coast of Herschel Island are characterized by steep cliffs about 50 m. high that are composed of silt and clay with only minor sand and gravel. Coastal change at Herschel Island between 1944 and 1970 is shown on Map No. 3. Retreat between 1954 and 1970 on the northwest coast varies from 0 to 25 m. On the north and northeast coasts retreat during the same period has been more general and varies from 0 to 33 m. The usual process of retreat there is undermining and collapse of blocks (Figure 38). Retreats of 25 m. between 1954 and 1970 on the north and south coasts are related to the presence of massive ground ice in the coastal cliffs (Map. No. 3). The Thetis Bay coast has been in general retreat since 1954, the amount of retreat ranging from 15 to 35 m. No significant retreat has occurred since 1954 on the southwest Herschel coast that faces the mainland.

## Herschel Island to the Babbage River delta

The low mainland opposite Herschel Island is in the area of net sediment accumulation and the shore is protected from the open ocean by Herschel Island and by a system of spits related either to the island or to the mainland.

Photogrammetric measurements of shoreline change for 1952 to 1970 between Roland Bay and Stokes Point are shown on Figure 39. During this 18-year period, this portion of the coast has receded an average of about 20 m. Some ground-ice slumps occur on the coast 3.5 km. northwest of Roland Bay.

Figure 36. Block slumping on coast between Clarence Lagoon and Alaska border; ice wedges exposed in cliffs. (17 July 1972; GSC 202261 - O)

Figure 37. Mantle of gravel and driftwood on top of 6-metre cliff near Clarence Lagoon. (17 July 1972; GSC 202261 - Q)

Figure 38. Block slumping, north coast of Herschel Island. (GSC 202261 - N; photo courtesy of V.N. Rampton)

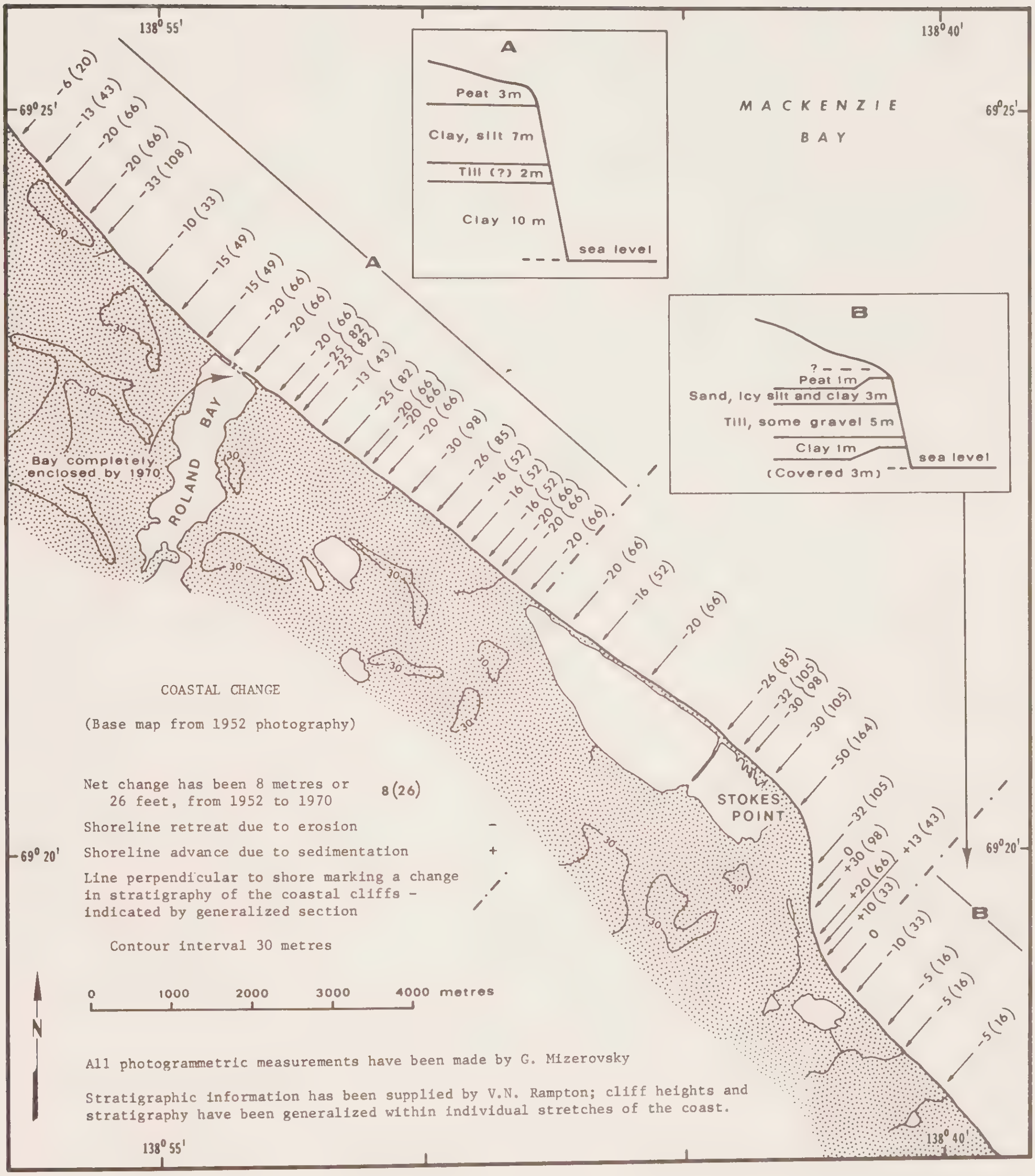



Figure 39. Roland Bay to Stokes Point - coastal change, 1952-1970.

Between Roland Bay and Stokes point the coast forms a gentle promontory. The cliffs here are exposed to direct wave attack, and wave refraction further concentrates energy on this part of the coast. Ground-ice slumps and some block slumping occur. Sediment derived from cliff erosion is dispersed by long shore currents northwestward toward Ptarmigan Bay from the one side of the promontory, and southeastward toward Phillips Bay from the other side.

General coastal recession is matched by the landward migration of the barrier beach at Stokes Point. The southeastward flow of the predominant longshore currents past Stokes Point has resulted in a seaward accumulation of 30 m. of sand and gravel in the lee of the Stokes Point promontory between 1952 and 1970.

Southeast from Stokes Point is another gentle promontory where the cliffs are unprotected by a beach. Photogrammetric measurements made along this cliff (Figure 39 and Map No. 4) indicate coastal retreat of less than 8 m. in this area between 1952 and 1970.

Coastal change from the Spring River delta southeastward to the Babbage River delta is shown on Map No. 4. In places the erosion since 1952-54 has affected only recent sediment of the beach and spit zones. Cliffs of older Quaternary sediments show no significant change between 1944 (where these photos were available) and 1970.

Marked retreat characterizes low coasts where sediments of drained thermokarst lakes are exposed to wave action. South of the Spring River delta, shore retreat between 1952 and 1970 has been about 25 m.; in a similar situation southeast of the Kay Point spit, retreat (1952-70) has locally been as high as 160 m.

## Kay Point to King Point

The most rapidly retreating coastal cliff area of the Yukon coast is the promontory forming Kay Point (Map No.4). Wave refraction concentrates energy on the cliffs here and strong longshore currents transport the reworked sediment away leaving no protective beach at the base of the cliffs. The sediments at Kay Point are fine-grained and ground-ice lenses and ice wedges are present in them. Well developed tundra polygons on the ground surface are being undermined and are tumbling into the sea. On the point itself there has been about 88 m. of retreat between 1952 and 1970. For 10 km. southeastward from Kay Point, retreat from 1952-70 has been in excess of 25 m.

Three near-shore echo-sounding profiles were run on the northeast side of Kay Point (see Map No.4 for locations; profiles are shown in Figure 40). The profiles are smoothly concave-up to depth of about 10 m., showing the influence of erosion due to wave action in forming the coast, and are simple except as Kay Point itself is approached (see P7 on Figure 40). There, strong longshore currents have resulted in the development of prominent offshore bars. At the bars water depths shallow to about 5 m. Wave action is not inhibited but the shore is protected from the impact of drifting ice floes. The uppermost sub-bottom reflection is thought to represent the contact between Recent silty sand that is the product of marine reworking of material derived from the coastal cliffs, and the underlying unreworked Quaternary sediment,possibly still frozen, of the type exposed in the cliff. The mantle of Recent Sediment is 1 to 4 m. thick. Its bottom contact has a relief of about 1 m. but locally as much as 3 m. This relief could be partly due to bottom scour produced by the grounding of floating ice in the near-shore area (similar to the features reported by Pelletier and Shearer, 1972).

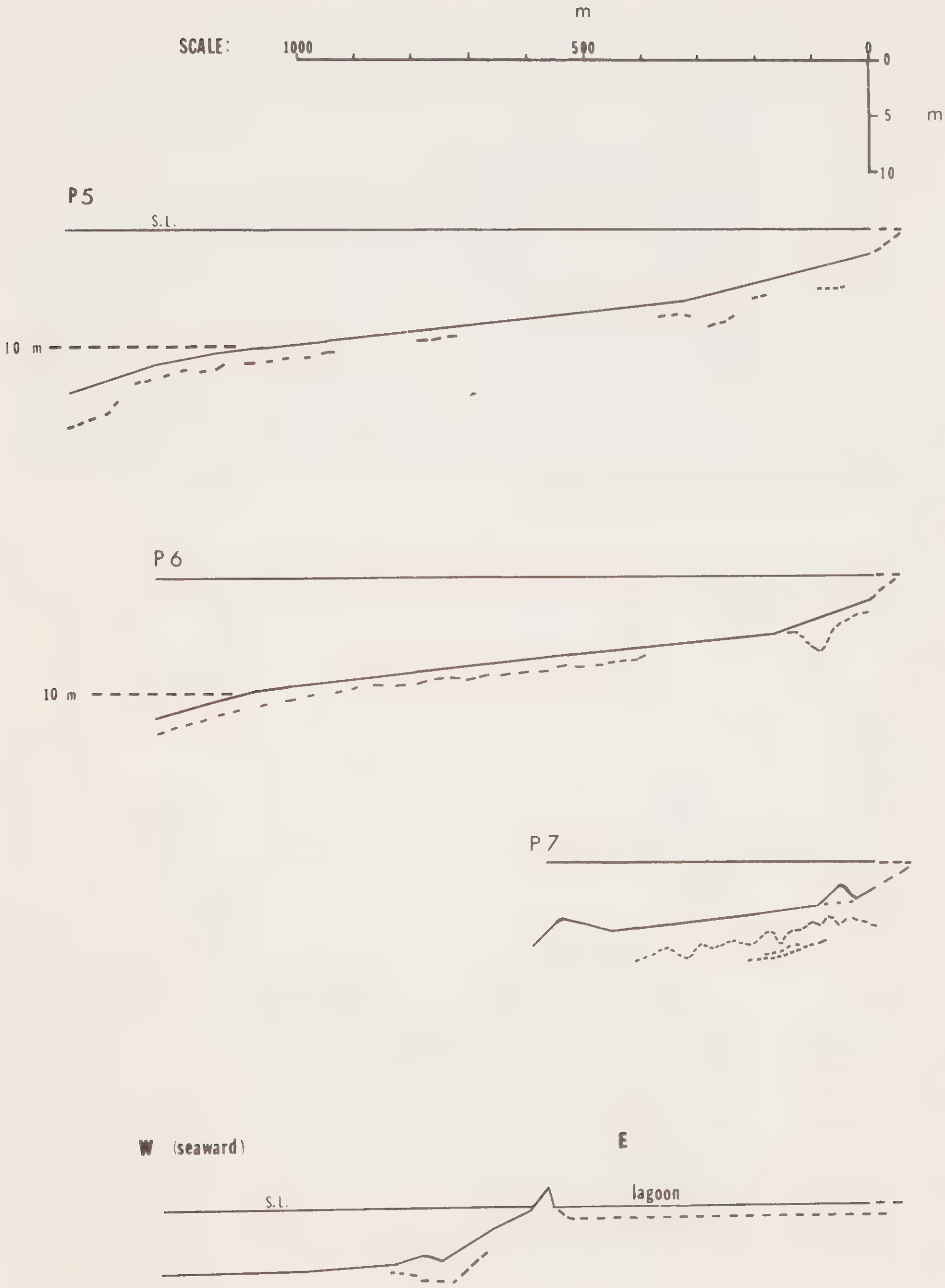



Figure 40. Near-shore bottom profiles in the vicinity of Kay Point and Kay Point spit (see Map No.4 for site location).

Figure 41. Mainland beach at King Point; note G. Wiik grave-marker on coastal cliff. (23 July 1972; GSC 202261 - R)

Figure 42. King Point spit enclosing the lagoon; stabilized scars of ground-ice slumps in foreground. (23 July 1972; GSC 202262 - A)

Southeastward to King Point (Map Nos. 4 and 5) coastal retreat has occurred with 1952-70 retreat of as much as 20 m., but long stretches of this coast have been apparently stable throughout this period. The coast for 5 km. west of King Point shows no measureable change in the period 1952 to 1970. Although the cliffs and gullies here are impressive, a 15-20 m. wide beach protects much of this area (Figure 41).

An interesting case in the annals of Yukon coastal retreat is that concerning the position of the gravemarker of G. Wiik with respect to the coastal cliff. He was buried at King Point in March, 1906 (Mackay, 1963; Figure 41). Between 13 July 1957 when Mackay visited the site, and 23 July 1972 when one of the present authors (McDonald) visited the site, no measurable retreat of the coastal cliff had taken place. This conforms with photogrammetric measurements reported above. Figure 42 also shows that scars of old ground-ice slumps at King Point are now stabilized with vegetation. Mackay reported that between 1906 and 1955 the R.N.W.M.P. (later R.C.M.P.) moved the grave-marker known distances inland three times to save it from the retreating coast. This provided a record of retreat there. However, Mr. S.W. Horrall, R.C.M.P. historian, and other present and past members of the R.C.M.P. have recently researched the archives and have reported many new details to the present authors (written comm., 1972, 1973). The complete history of the grave-marker appears to be as follows:

(a) March, 1906; G. Wiik was buried at King Point about 50 yards back from a small coastal cliff on the site of Roald Amundsen's meteorological station. (There is some uncertainty about this distance; Mackay (1963) reports it to be 5 to 10 m.);
(b) 1908: the grave was being undermined by the sea;
(c) 6 August 1909; R.N.W.M.P. moved the coffin to a higher elevation 200 yards back from the high-water mark. The new grave was marked with a wooden post and headboard;
(d) 1921: grave was observed by S.T. Wood, R.N.W.M.P., but headboard had disappeared, apparently scrounged by local people;
(e) 1937: no sign of the grave could be found by members of the Aklavik detachment of R.C.M.P.;
(f) 1938: a new substantial cross (the one still there in 1972) "was erected by Aklavik detachment members on what they believed to be the approximate grave site" (S.W. Horrall, written comm.);
(g) 1955: cross had fallen down so Inspector W.G. Fraser, R.C.M.P., moved it a distance variously reported as 25 to 300 feet, not because of erosion but merely to a spot where rocks were plentiful enough that the cross could be securely banked up.
(h) since 1957: no significant recession of the coast.

S.T. Wood told Inspector Fraser of having moved the grave in 1924 (W.G. Fraser, written Comm., 1973) but no record of this exists in the R.C.M.P. Archives.

This evidence provides a somewhat unreliable chronicle of coastal retreat at King Point. A rigorous interpretation confirms only 5 to 10 m. of coastal retreat since 1906, although it is possible that there has been about 200 m. of retreat between 1906 and 1957 and none since.

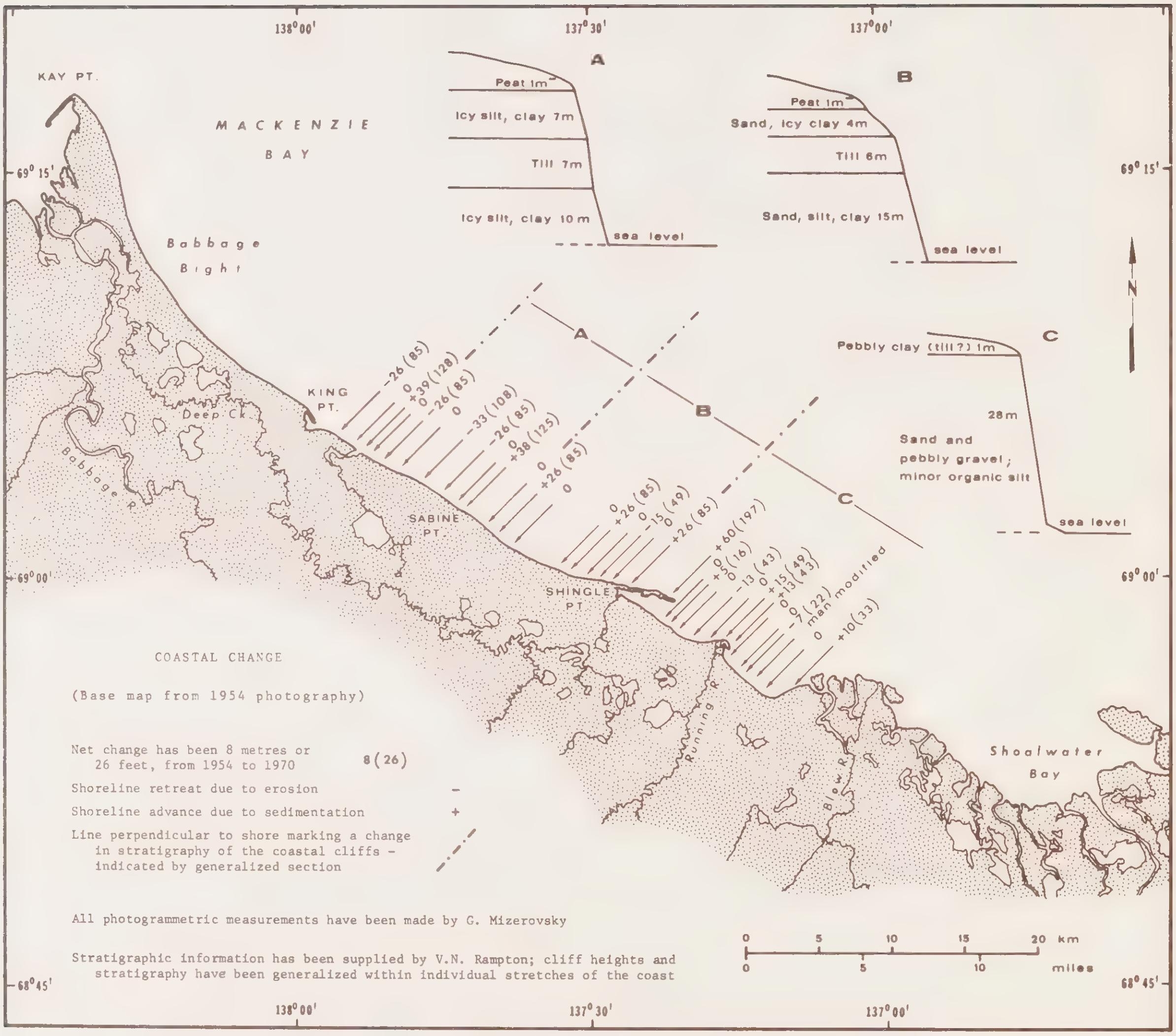



Figure 43. King Point to Blow River delta - coastal change, 1952-1970.

Figure 44. Block slumping between King Point and Sabine Point.
(22 July 1972; GSC 202262 - E )

Figure 45. Mainland beach, Sabine Point; note low truncated end of debris-flow lobe in centre.
(22 July 1972; GSC 202261 - S)

King Point to Sabine Point

The coast between King Point and Sabine Point is characterized by high (30-40 m.) cliffs that locally are protected from wave erosion by narrow beaches at their bases. Details of coastal change are shown on Map No. 5 and Figure 43. Retreat figures from 1952 to 1970 vary from 0 to 50 m. The large retreat (50 m.) at the southeast end of King Point lagoon may be related to strong shore currents that developed as the spit advanced southeastward toward the land to completely close off the lagoon. The general process of retreat in this zone has been undermining of the cliff followed by block slumping (Figure 44).

Sabine Point to Blow River delta

From Sabine Point to the Blow River delta, coastal change from 1952-1970 has been characterized more by beach and spit growth rather than by erosion of coastal cliffs (Figure 43). Retreat of 5 to 15 m. has been measured in 3 localities along this portion of the coast, although narrow mainland beaches (Figure 45) protect most of the cliffs. In Figure 45 the low truncated end of a debris-flow lobe can be seen at the coast. The material was derived from a ground-ice slump behind and delivered to the sea through a narrow port. The sea has redistributed the sediment and eroded the lobe back to give a fairly straight coast.

Local erosion on the low northwestern lobe of the Blow River delta has amounted to 20 m. since 1952.

6.2.3. Coastal Sedimentation

General patterns of near-shore sediment movement

Strong longshore currents occur in the near-shore areas of the Yukon coast and have resulted in distinctive patterns of near-shore sediment accumulations. The general directions of longshore transport, as inferred from the distribution of spits, beaches, and promontories, are shown on Map. No. 2. Sediment delivered to the coast by rivers and derived from coastal cliffs by erosion are distributed by longshore currents to major areas of sediment accumulation, or sediment "sinks". Although sources of sediment are numerous along the coastal cliffs, there are also long stretches of the coast which are not actively retreating. The mainland coast in these areas is protected from erosion by relatively stable (though narrow) beaches or by spits or barrier beaches lying short distances offshore.

The major "cells of longshore sediment movement on the Yukon coast can be summarized as follows (Map No. 2):

(a) From a gentle promontory 15 km. west of Komakuk Beach longshore currents take sediment westward past Clarence Lagoon into Alaska where they are deposited in Demarcation Bay;

(b) From this promontory currents disperse sediment eastward about 50 km. to the shallow protected embayment between Herschel Island and the mainland. This embayment is a major sediment sink. Sediments are fed into it by longshore currents from both the east and west sides of Herschel Island. From a gentle promontory 5 km. northwest of

Stokes Point sediment is dispersed northwestward 20 km. to Herschel Island sediment sink;

(c) Between the promontory 5 km. morthwest of Stokes Point and a gentle promontory about 5 km. southeast of Kay Point, sediments are fed into Phillips Bay - the second major sediment sink on the Yukon coast;

(d) Sediment is transported southeastward from the gentle promontory southeast of Kay Point to finally be deposited in Shoalwater Bay - the third major sediment sink on the Yukon coast.

The longshore currents flow in response to wind-induced heads of water. Consequently they will vary with the wind conditions at any one site. In the case of the Herschel Island and Phillips Bay sinks, currents feeding in from both sides simultaneously are probably accompanied by strong escape currents that return the water to the sea. Details of these current patterns are not known. For many wind directions it is probable that longshore currents feed in from only one direction at any given time, thereby permitting escape of water out the other side of the sink.

Echo sounding in the vicinity of Kay Point (Figure 40) and Nunaluk spit (Map No. 6) indicates that offshore bars become better developed as one progresses farther downstream in a longshore current direction (cf. P5 to P6 to P7, and P9 to P10 to P12 to P13 of Figure 40 and Map No 6, respectively). This is probably a response to a strengthening current in the downdrift direction.

There are also indications that some bedload moves perpendicularly to the shore. Asymmetric sand waves with steep sides toward shore indicate onshore movement of sediment. These have been observed in Phillips Bay and in P9 of Map No. 6. Channels oriented at right angles to the shore and characterized by levee-like ridges at their margins have been observed off Nunaluk spit. They occur in 2.6 m. of water and are 2.1 m. deep with a top width of 20 m. Levee heights are 0.6 m. These have been interpreted as rip-current channels (Map No. 6) and occur where the eastward flowing longshore current encounters a water flow westward out of the Herschel Island sink.

Near-shore currents and surf activity are important sorting agents for sediment in motion on the coasts. Silt and clay is transported as suspended sediment to more offshore locations, and gravel and sand is stored in such near-shore traps as beaches, spits, offshore bars, and lagoons.

## Beaches and spits - general form and sediment types

Most shore accumulations of sand and gravel take the form of beaches and spits. Their principal characteristics will be discussed here - preliminary to a discussion of specific occurrences.

Driftwood is common along the entire coast and is concentrated on beaches and spits. Pebbles in the beaches and spits are generally quartzitic and relatively resistant to abrasion. In most cases they are probably derived from cliff sections within a few kilometres of their occurrence in the beach or spit. In some cases, however, the pebbles may have been derived from nearby gravel bodies that have long since disappeared due to general coastal recession. If these modern gravels were mined out, the sediment body might never recover.

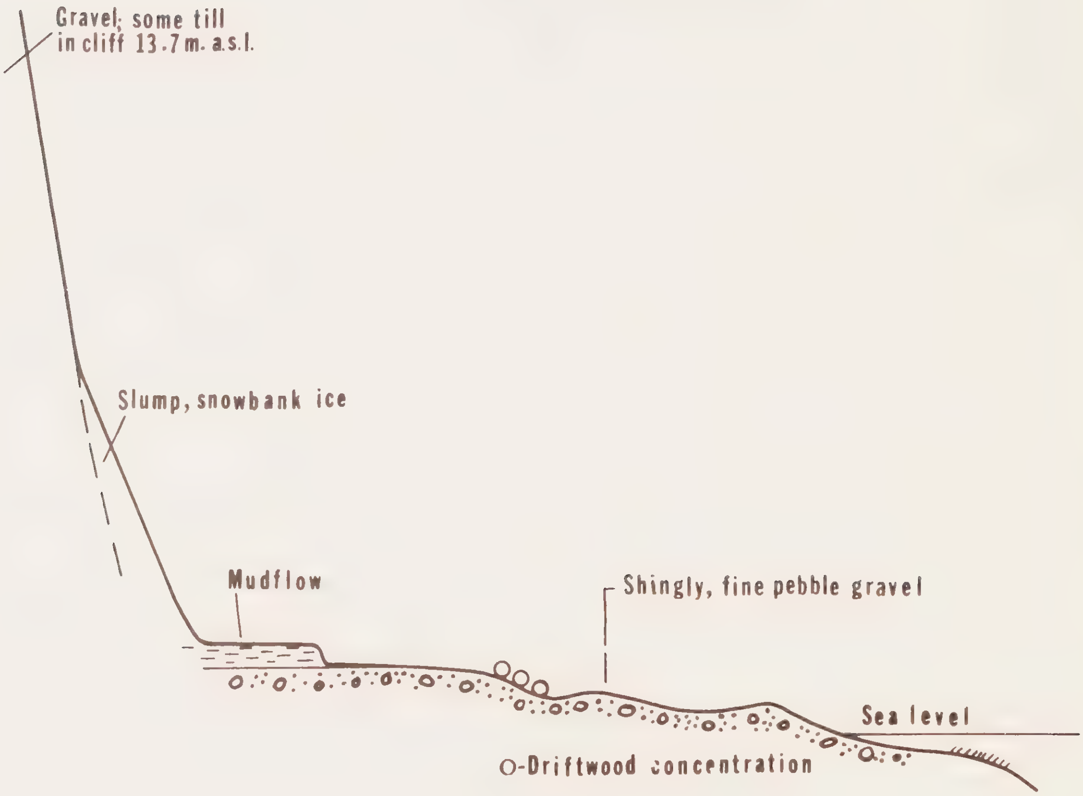



Figure 46. Mainland beach at King Point, below G. Wiik grave-marker.


Figure 47. Mainland beach below slump near Sabine Point.

The maps of coastal change show considerable accumulation, erosion, and relocation of these near-shore sediment bodies. Although some of these changes represent long-term influences, others could reflect only the impact of a particular storm a few days before the aerial photograph was taken. Detailed configuration of topography on these sediment bodies is ephemeral. Ice push (Figure 33) or storms can cause sudden distortion that more normal wave conditions immediately set about to repair.

Mainland beaches at the base of coastal scarps are commonly less than 20 m. wide (see Figures 35,41 and 45). The beaches of Figures 41 and 45 are schematically represented as Figures 46 and 47, respectively. Their micromorphology reflects sediment units accreted during particular storms. Such beaches typically consist of shingly, fine-pebble gravel to sandy medium-pebble gravel. Thickness of gravel is unknown but is thought to be in the order of one to two metres in beaches of the type shown in Figures 46 and 47. Mud flows derived from the cliff commonly encroach over the landward edge of the beach and may occur as thin sedimentary units lower in the beach sequence as well.

Spits throughout the coastal zone show similar characteristics (Figure 48):

(a) They have a relatively abrupt slope on the seaward face and a more gentle slope leading back to the lagoon. The seaward face reflects the surf influence whereas washover fans, formed when the spit is inundated by storm tides, control the back slope;

(b) Washover fans occur in lobe-like aprons fanning out across the backslope toward the lagoon. Considerable sediment is transferred to the lagoon during washovers;

(c) Grain-size of sediment decreases from sandy pebble gravel on the seaward margin to coarse sand, occasionally silty and slightly (< 5 per cent) pebbly, on the lagoon side;

(d) Driftwood tends to be concentrated near the crests of the spits;

(e) Minor amounts of sand are entrained by wind and redeposited on the spit in layers 2 to 3 cm. thick;

(f) Narrow beach facies commonly occur on the lagoon side and result from small waves generated within the limited fetch of the lagoons.

Frost tables in the Kay Point spit were probed on 12 June and again in July 1972. The profiles (Figure 48) are presented here insofar as they are probably representative for coastal spits throughout the Yukon coastal plain. Sea ice adjacent to the spit broke up between about 1 June and 10 June 1972. The frost table on 12 June lay about 50 cm. below the surface, but even after a month of warm weather and being bathed in sea water on both sides, the frost table had been lowered only about 50 cm. more.

## Areal variations and stability of near-shore sediment bodies

This discussion will concentrate on shore and shallow-water accumulations excluding major deltaic bodies which are covered in a later section.

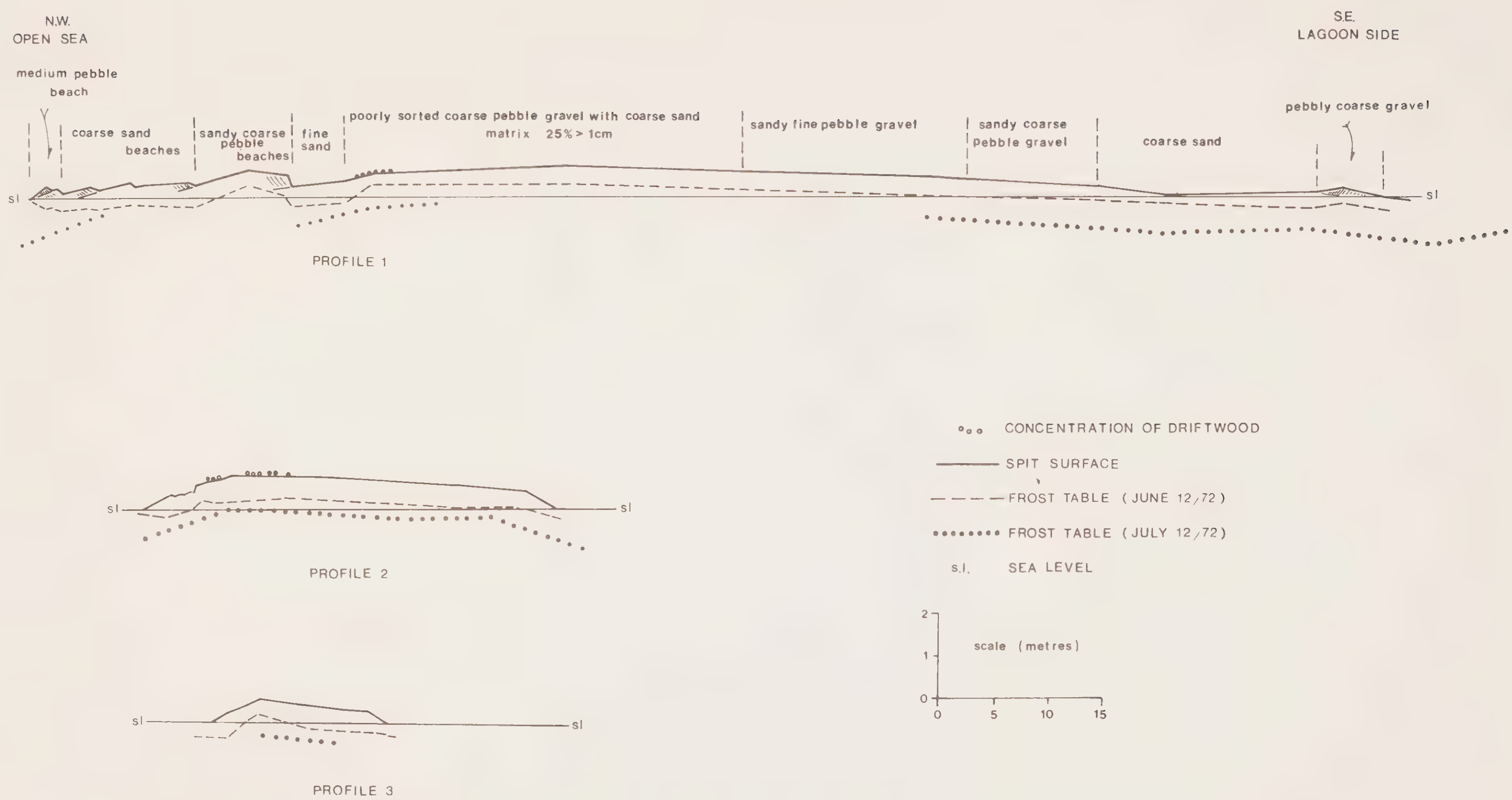



Figure 48. Cross-profiles of Kay Point spit, showing positions of frost table on June 12 and July 12, 1972 (see Map. No.4 for profile locations).

International border to Komakuk Beach

Except for the bay-mouth bar enclosing Clarence Lagoon, and the minor deltas of Craig Creek and an unnamed stream within Clarence Lagooon, this portion of the coast is characterized by narrow mainland beaches below the coastal cliff (Figure 35).

Komakuk Beach to Herschel Island

At Komakuk Beach, Fish Creek delivers an abundant supply of sandy fine-pebble gravel to the coast at a promontory. Longshore drift disperses this sediment eastward to Nunaluk spit (Map No. 6) which borders the coast eastward to the Herschel Island sediment sink. As can be seen in Figure 49, the spit protects the mainland shore from erosion by absorbing the impact of the open ocean waves and by preventing drifting ice floes from getting into the lagoon.

Nunaluk spit is characterized by numerous spurs (Figure 49) projecting into its lagoon. These spurs may result from water current patterns in the lagoon (Zenkovich, 1967). They are perpendicular to the spit, extend almost across the lagoon in places, and are regularly spaced along the easternmost of the two completely enclosed lagoons.

The spit is continuous until it is opposite the Malcolm and Firth Rivers. Here, three perforations in the spit are maintained by river discharge and three barrier islands (numbered 1, 2, 3, on Map No. 6) represent continuation of the spit. Near echo profile P9 (Map No. 6) the main spit is anchored to an island of older clay and silt. The lagoons tend to be shallow (probably 2 m. deep or less) and they act as sediment traps, storing sediment brought from the ocean side by washover and from the landward side by rivers.

The sediment on Nunaluk spit is characteristically fine to medium pebble gravel except for a markedly finer facies (sand) on barrier islands Nos. 2 and 3. This finer facies may be due to escape currents flowing westward from the Herschel Island sink that cause occasional rapid deceleration of the eastward flowing longshore current.

Photogrammetric measurements of Nunaluk spit from 1952 and 1970 aerial photographs indicate the following (Map No. 6):

(a) No net displacement of the spit, in either an onshore or offshore direction has occurred;

(b) No net change in width has occurred;

(c) New spit tips have extended eastward the following distances due to sediment delivered by the longshore current:

   (i) main spit - 690 metres
   (ii) barrier island no. 1 - 235 metres
   (iii) barrier island no. 2 - 615 metres
   (iv) barrier island no. 3 - 675 metres

(d) Westward extensions of recurved barrier-island tips have occurred on islands no. 3 and 2. These are probably due to the currents escaping westward from the Herschel Island sink.

Thickness of spit gravels can only be surmised. The main outlet for Firth River discharge lies between barrier island no. 1 and the main spit (see P11 on Map No. 6.). The channel here is 5.5 m. deep, has a top width of 55 m., and its bottom lies 7.0 m. below sea level. The channel rapidly becomes poorly defined in a seaward direction. Such

Figure 49. Nunaluk spit with pack ice on the seaward side; driftwood marks crest of spit. (17 July 1972; GSC 202262 - D)

channels form bathymetric traps that interupt longshore movement of sediment. Infilling on the up-current side may cause lateral migration of a channel and thus of the river mouth. This process would lead to the formation of spit gravel that in the vicinity of these river outlets may extend to 7 m. below sea level. In this case, spit gravel would overlie drowned river gravels of the Malcolm and Firth fan deltas.

Near-shore profiles were run with the echo sounder adjacent to Nunaluk spit. Profile P9 is simple concave-up, showing the influence of wave energy, and showing low sand waves probably migrating on-shore. In profiles P10, P12, and P13 offshore bars are well developed and indicate strong longshore current activity. The bars, probably composed of fine to medium sand, are 1-2 m. high, 75-350 m. wide, and their crests lie at water depths of 2-6 m. Sub-bottom reflections indicate a prominent reflector at a depth of 2-3 m. below the bottom. This might represent the upper surface of the underlying older gravel of the Firth River fan delta.

## Herschel Island

Avadlek spit extends southward from the west side of Herschel Island (Figure 50). Longshore currents feed sediment southward along it into the Hershel Island sediment sink. Photogrammetric measurements from 1944, 1954 and 1970 aerial photographs (Map No. 3) show no significant change along most of the length of the spit. The southern tip has undergone minor change but the spit has not been measurably extended since 1944. This is due to the strong currents that sweep past the south end of the spit and that maintain a channel there 11 m. in depth (P14 on Map No.6).

A small spit used to extend southward past the southern tip of Herschel Island (Map No. 3). Due to retreat of the adjacent coast, this spit was forced to shift westward. Since 1970 it has been breached near the island and the extension of the spit has now been levelled to where it is largely inundated at normal high tide.

The small spit at the abandoned settlement of Herschel has extended 150 m. since 1944 and has become broader.

## Herschel Island to Babbage River delta

The large embayment 15 km. northwest of Stokes Point is completely enclosed behind a bay-mouth bar. From here northwestward 9 km. to Catton Point the bar takes the form of a spit locally attached to the mainland and at one place anchored to a prominent island composed of older, fine-grained sediment. Longshore currents sweep northwestward along it carrying sediment to the Herschel Island sediment sink. The entry of these currents into the sink is indicated by the strongly recurved nature of the tip of the spit.

Between the embayment and Stokes Point mainland beaches are thin or absent. At Stokes Point, a spit that advanced southeastward has totally enclosed a shallow lagoon. Beach ridges are accreting onto the southeast side of this complex (Figure 39). This is accompanied by a shoreward - shift of the seaward edge of the main spit as processes act toward a general straightening of the shorelines.

Shoreline changes between the Spring River and Babbage River deltas have been measured photogrammetrically (Map No. 4). Sediment delivered to the coast by the Spring River is abruptly dispersed southwestward toward Phillips Bay by longshore currents. One prominent bar tip, 95 m.

Figure 50. Avadlek spit; Herschel Island in the background. (16 July 1972; GSC 202261 - T)

Figure 51. Seaward edge of Kay Point spit, looking southwest. (10 July 1972; GSC 202261 - M)

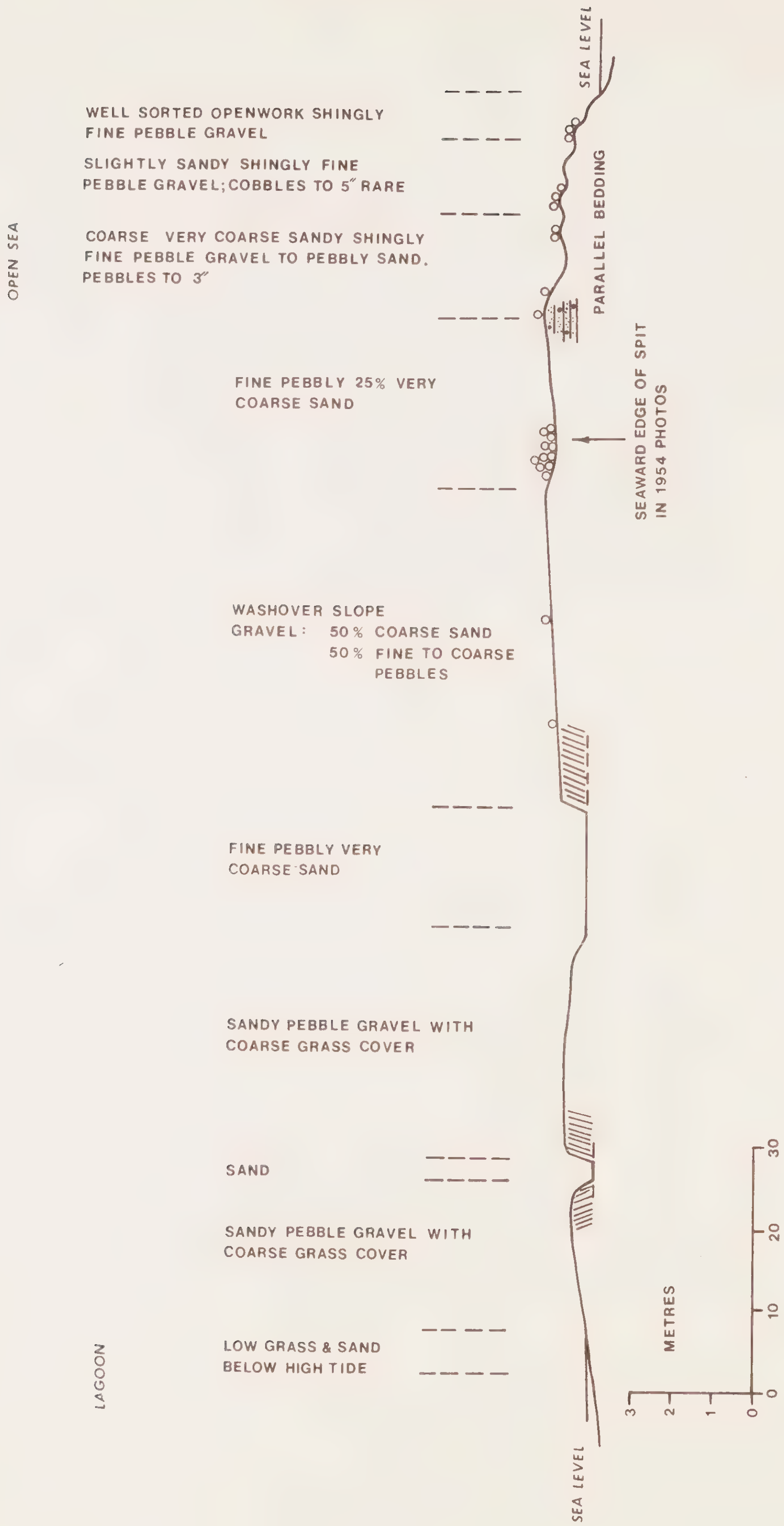



Figure 52. Cross-profile and sediment types, Shingle Point spit.

wide,has been extended 610 m. between 1952 and 1970.

Kay Point spit

Kay Point spit extends from Kay Point southwestward for 4.2 km. into Phillips Bay (Figure 51). It is attached to Kay Point at its north end, and is evidently fed by longshore currents sweeping around the point bringing sediment derived from retreat of the coastal cliffs.

Retreat of the Kay Point cliffs (Map No. 4) has forced the spit to shift toward the southeast. This shift evidently progresses through time down the spit; only the northernmost 500 m. of the spit is adjusted to the present position of the point. Strong currents developed in the curvature 500 m. southwest of the point and had breached the spit there prior to 1970. Presumably this breach will heal, or maybe be transferred southwestward. The southernmost 1.8 km. of the spit underwent considerable modification between 1952 and 1970. The spit tip has extended 450 m. in that time but without detailed study of nearshore topography it would be difficult to estimate the rate at which new sediment was being added to the spit complex.

A near-shore bottom profile in the vicinity of Kay Point spit (P8 on Figure 40; see Map No. 4 for location) indicates that as the spit shifts toward the lagoon a great deal of sediment must be reworked if the seaward profile is to remain in equilibrium. Some of this sediment will be transferred to the lagoon, some will contribute to elongation of the spit, the spit may become broader, and some sediment may be transferred farther out into Phillips Bay. A small offshore bar is shown in Figure 40. Offshore bars become more numerous and better developed southwestward along the seaward margin of the spit.

Kay Point to Sabine Point

From Kay Point to King Point the coast is characterized by steep cliffs at the foot of which mainland beaches are either absent or very narrow.

At King Point, a bay-mouth bar about 100 m. wide and composed of sandy pebble gravel has grown eastward 425 m. between 1952 and 1970 to completely enclose the lagoon (Figure 42 and Map No.5).

Between King Point and Sabine Point the coast has straightened in the interval between 1952 and 1970 partly by coastal retreat and partly by local broadening of bay-mouth bars and mainland beaches.

Sabine Point to Blow River delta

From Sabine Point to Shingle Point the coast has been relatively stable since 1952. Mainland beaches of pebble gravel have locally broadened by as much as 25 m. (Figure 43) and have contributed to a straightening of the coast.

The Shingle Point spit (Figure 43) has broadened in a seaward direction as much as 60 m. and has lengthened about 150 m. between 1954 and 1970. Comparison of 1972 conditions with a photograph taken by J.R. Cox in 1914 (Canadian Arctic Expedition, 1913-16; GSC photo no. 39607) shows that considerable sedimentation has occurred in the lagoon in the area where the spit is attached to the mainland. The seaward side of Shingle Point spit (Figure 52) is composed of shingly fine- to coarse-

Figure 53. Firth River fan delta; Nunaluk spit in background at right.
13 July 1972; GSC 202261 - U)

Figure 54. Flat of Babbage delta plain at edge of distributary channel; stake marks site of drill hole 517-SP (see Map No. 4 for location). (10 July 1972; GSC 202262 - G)

Figure 55. Irregular surface due to thermokarst action near front of Babbage delta. (4 July 1972; GSC 202261 - V)

pebble gravel. This grades along washover fans to only slightly pebbly coarse sand on the lagoon side. The spit crest is as much as 1.5 m. above sea level.

### 6.2.4. Major Coastal Deltas

Three different delta types are discussed briefly here:

(a) the Firth River fan delta which essentially is the intersection of the alluvial fan surface with the sea;
(b) the estuarine delta being built by the Babbage River where deltaic sediments are accumulating in an embayment; and
(c) the open coast deltas of the Running and Blow rivers.

#### Firth River fan delta

The Firth River is depositing a broad but relatively thin wedge of deltaic sand and silt in the lagoon behind Nunaluk spit (Figure 53). Plumes of suspended sediment are carried directly out to be deposited offshore. The surface and submarine form results from intersection of the sea with an alluvial fan that, at times of lower sea-level, extended far beyond the present shoreline. Streams on the fan surface rapidly decelerate as the lagoon is approached and much of the sediment delivered to the coast is being stored in the lagoon. Some coarse bedload passes seaward in the outlet channels batween barrier islands, where it is distributed southeastward by the longshore current.

#### Babbage River delta

The Babbage River delta (Map No. 4) is composed of sediment discharged into the head of Phillips Bay by the Babbage River. It has a flat subaerial surface (Figure 54 that lies 0.5 to 2.0 m. above sea level. The occurrence of driftwood (Map No. 4) along contours far back from the delta front indicates that storm tides sometimes inundate most of the delta plain.

Four holes were drilled on the delta surface (see Map No. 4 for locations). Hole 516-SP was drilled on an island characterized by a peculiar rough topography (Figures 55 and 56). Local relief is >2 m. and ponds occupy the closed depressions. Ice commonly forms the floors of the ponds. The topography is thought to be of thermokarst origin. The generalized sample log of hole 516-SP was:

| | |
|---|---|
| 0 - .8 m. | wood detritus and silty peat |
| .8 - 2.2 m. | peaty silty sand with 15-50% ice lenses (by volume) |
| 2.2 - 2.6 m. | silty peat with 45% ice lenses |
| 2.6 - 4.3 m. | 95% pure ice with 5% silt |

The other 3 holes encountered peaty silty sand with an excess ice content greater than 10% and occurring in pure ice lenses as thick as 25 cm.

It is possible that the massive ice body underlying this front part of the Babbage delta is either an old aufeis over which sediments were subsequently deposited or is ice that formed in association with an open system pingo, the surface of which has subsequently been degraded. It exists at the downstream end of a network of delta distributaries as deep as 7.5 m., in and beneath which winter flow may have persisted while the shallower seaward zone was completely frozen. This would create a situation favourable for the development of an aufeis or an open system pingo.

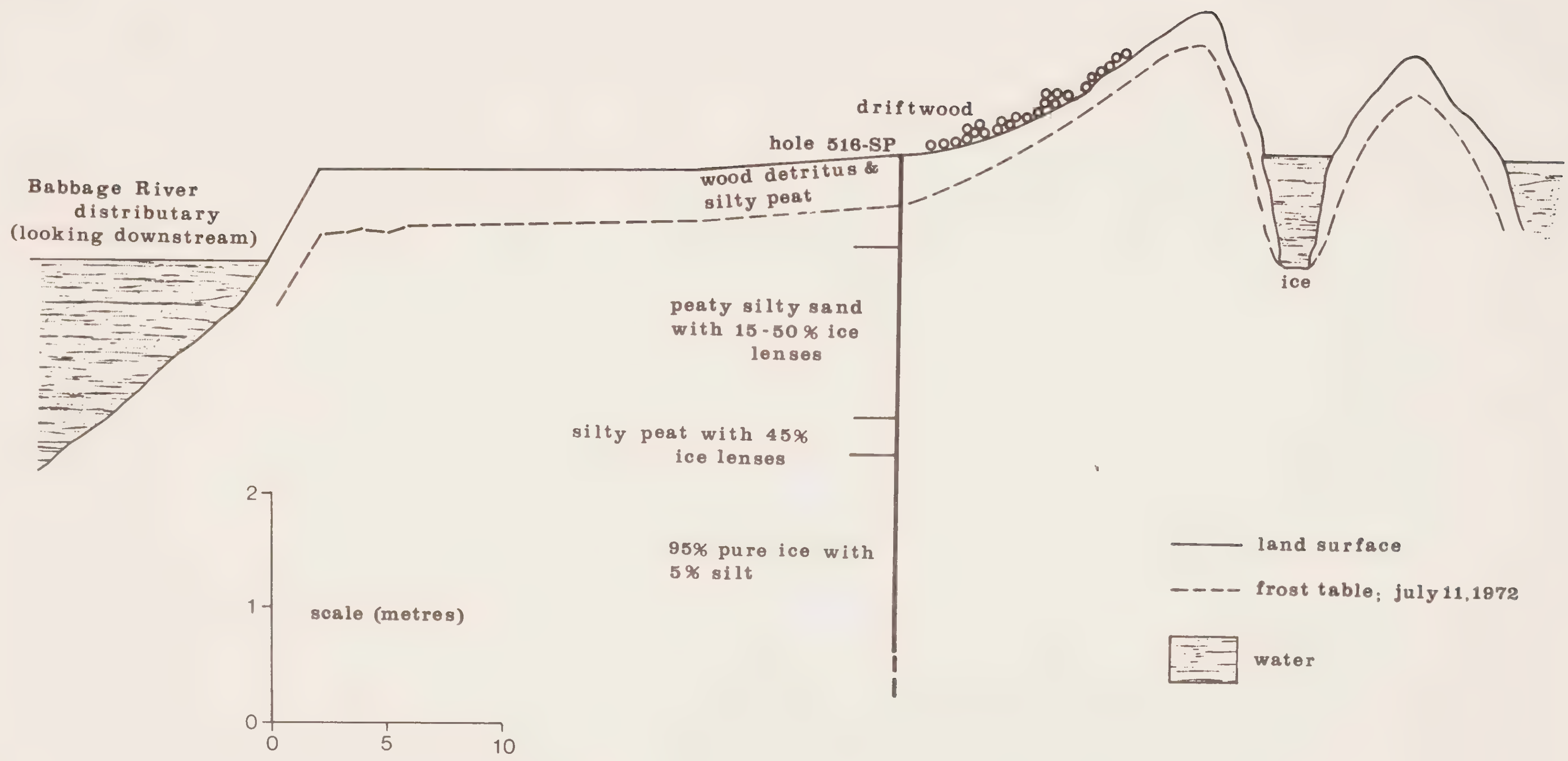



Figure 56. Topography, frost table, and stratigraphy of hummocky surface near front of Babbage River delta (see Map No.4 for location).

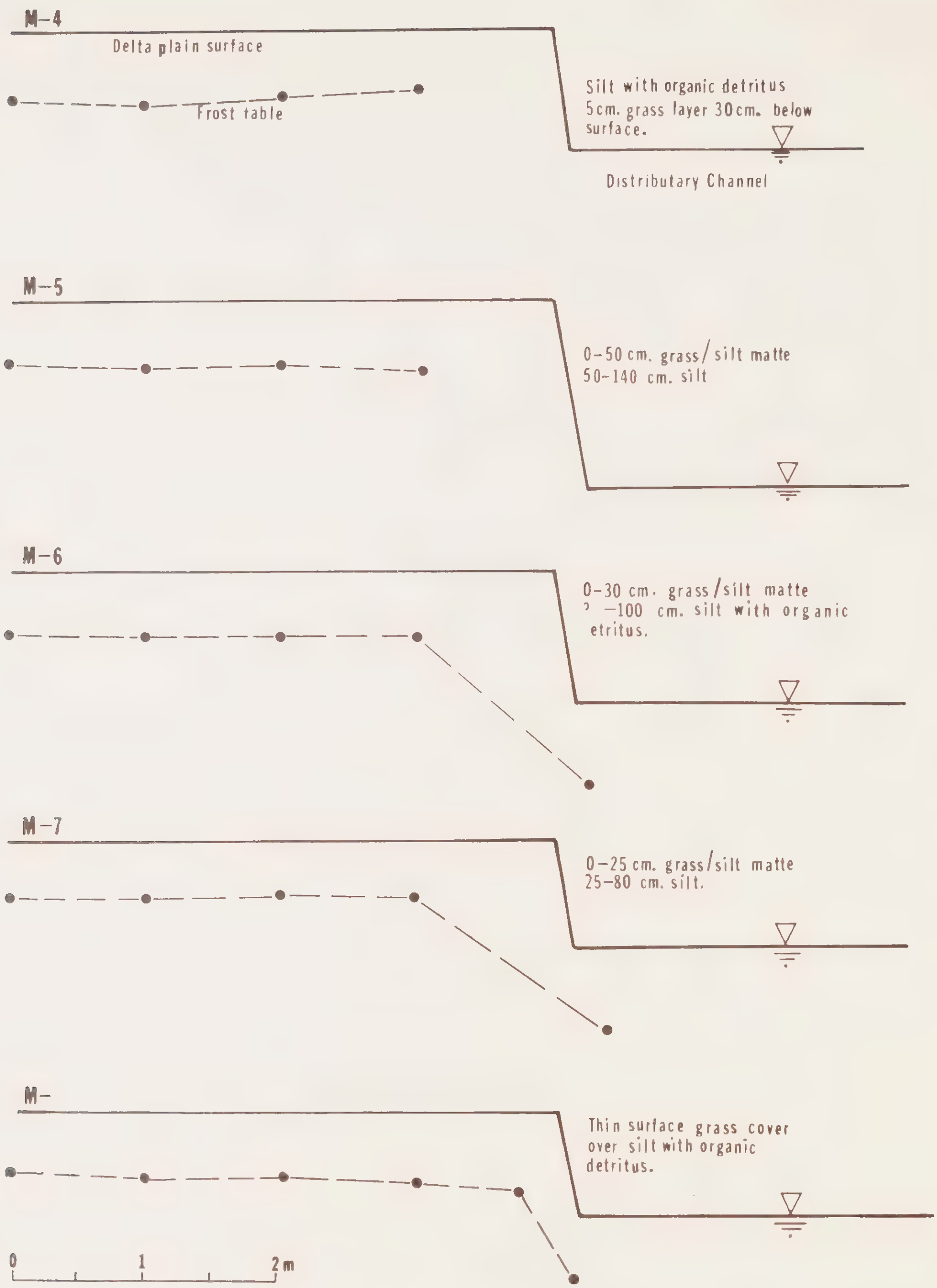



Figure 57. Position of frost table on 11 July 1972, beneath surface of Babbage delta plain immediately adjacent to distributary channels (see Map No.4 for site locations).

Figure 58. Intertidal bar at mouth of Babbage River; shovel is 50 cm. long; frost table on 10 July 1972 was 50 cm. below surface. (10 July 1972; GSC 202261 - W)

Depth of the frost table below the flat delta surface was probed in many places adjacent to distributary channels on July 11, 1972 (Figure 57). The frost table lay 45-50 cm. below the flat subaerial surface and was located beneath water at the channel edge with a probe at about the same depth as below the channel bottom with an echo sounder. The frost table in an intertidal bar (Figure 58) located beyond the vegetated delta front was 50 cm. below the bar surface on July 10, 1972. This was established with a probe and confirmed by digging a small pit.

Echo-sounding in the distributary channels of the Babbage delta (see Map No. 4 for tracks) provided some sub-bottom data. In Figure 59 (top) a strong reflection is present 0.6 to 1.0 m. below silty sand on the channel bottom, and deltaic foresets 3 m. thick are visible below this. In Figure 59 (middle) the prominent reflector about 0.6 m. below the channel bottom, has been truncated by one side of a deeper channel but is visible under the other side where it is mantled by 2 m. of silty sand. In Figure 59 (bottom) a series of dunes about 20 cm. high and 11 m. in wave length can be seen in water depth of 1.4 m. About 0.6 m. below the prominent reflector is again visible. Less than 10 m. from the location of Figure 59 (bottom) the frost table was probed at 52 cm. below the bottom which in turn was under 60 cm. of water.

It is thought that this prominent reflector is the frost table. In the case of Figure 59 (middle), truncation of the frost table may have occurred during spring flood and the unfrozen mantle on the upstream side of the deeper channel may record infilling since the spring flood. If this is indeed the frost table, then two interesting points can be brought out:

(a) Why should the frost table be within 60 cm. of the channel bottom where water depth is as great as 5.8 m.? It is unlikely that the river freezes to the channel bottom in winter; and

(b) Sub-bottom echo profiling can provide a measure of maximum depth of river-bed scour during the spring flood. Sub-channel frost would inhibit scour, and the frost table would give a maximum value for spring flow depth at that place.

Photogrammetric measurements shown on Map No. 4 indicate the amount of progradation that has taken place along the Babbage delta front between 1944 and 1970.

Sediments on the delta surface (Figure 60) are silt, with about 15% clay, 10-30% sand, and admixed fine organic detritus. Study of Figure 60 leads to the following generalizations:

(a) Till and colluvium, with a silt/clay ratio of 2/1, are a principal source of sediment to the lower Babbage system; river-worked sediments adopt a silt/clay ratio of 4/1 (dashed line in Figure 60); it is apparent that clay is moved through the system as washload and is being deposited at sea beyond Phillips Bay;

(b) Silt is carried down the river as washload but is concentrated in the delta, probably a result of rapid deceleration of flow both as it encounters the sea and as it overflows the banks; and

(c) Channel-bottom sediment has a silt-clay content similar to bottom sediments in Phillips Bay. (Many fewer samples were collected from the Running River and Blow River systems,

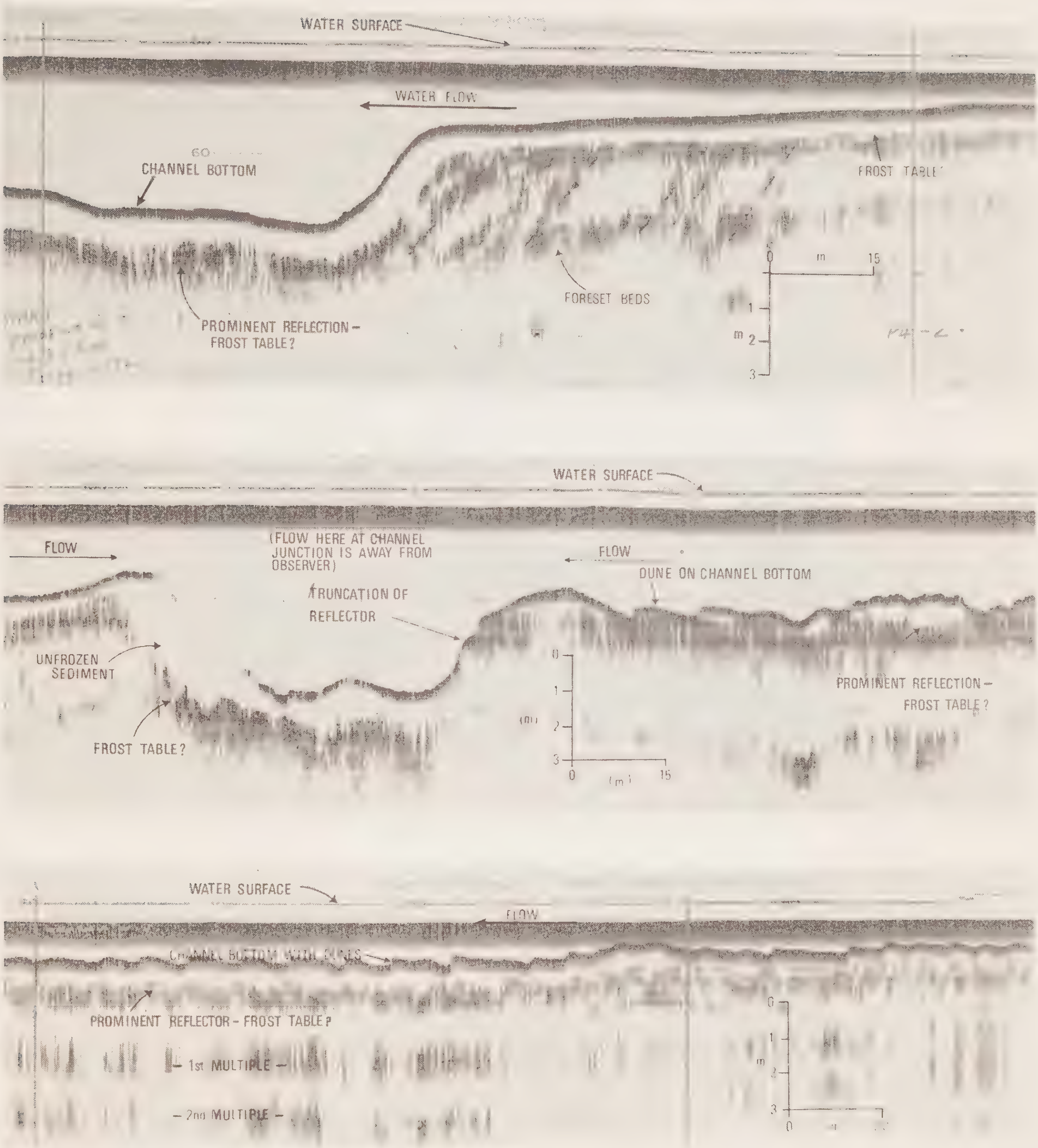



Figure 59. Echograms from Babbage River delta distributary channels.

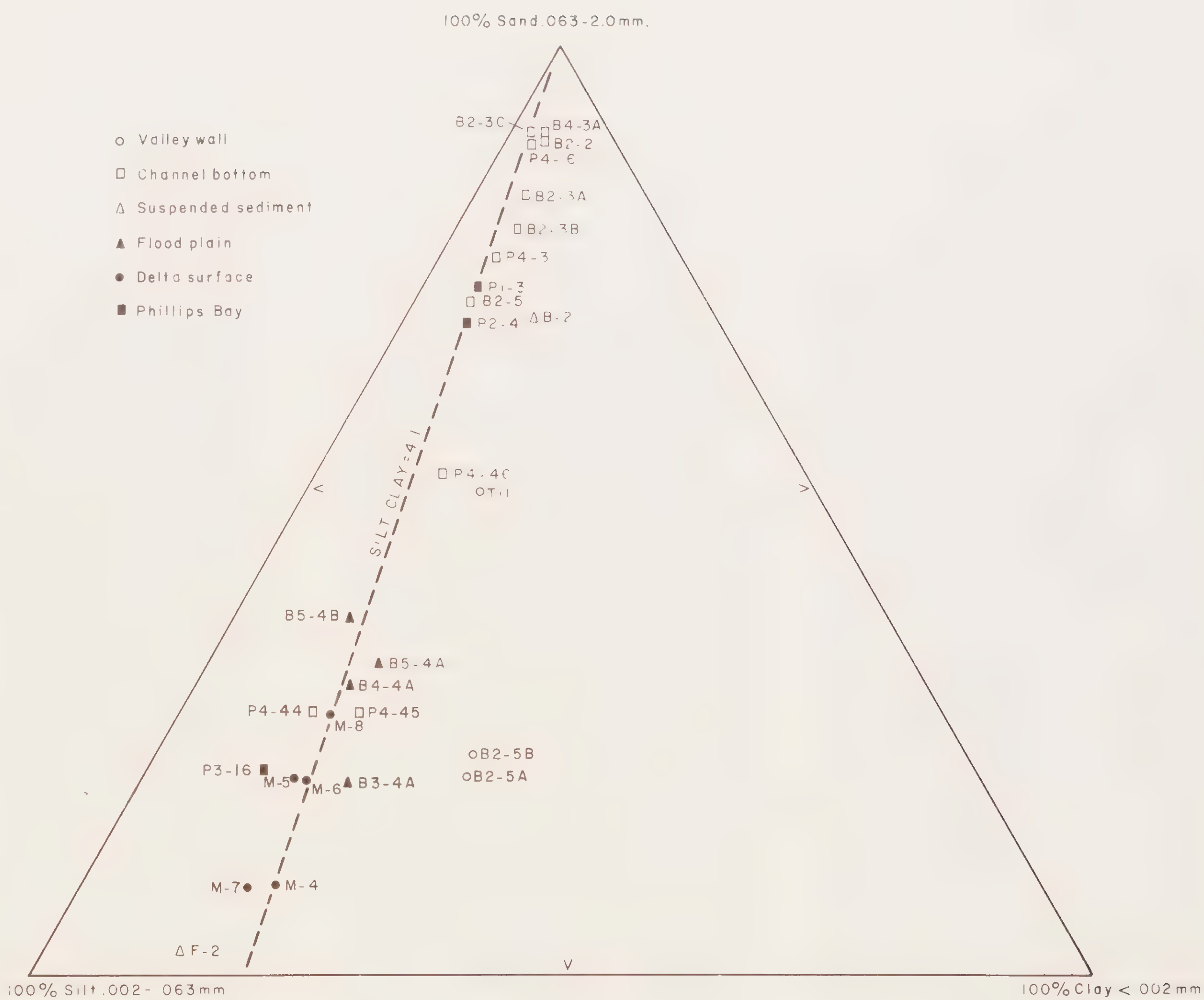



Figure 60. Sediment textures (fine fraction) in Babbage River system.

Figure 61. Seaward margin of Running River delta, looking west. (21 July 1972; GSC 202261 X)

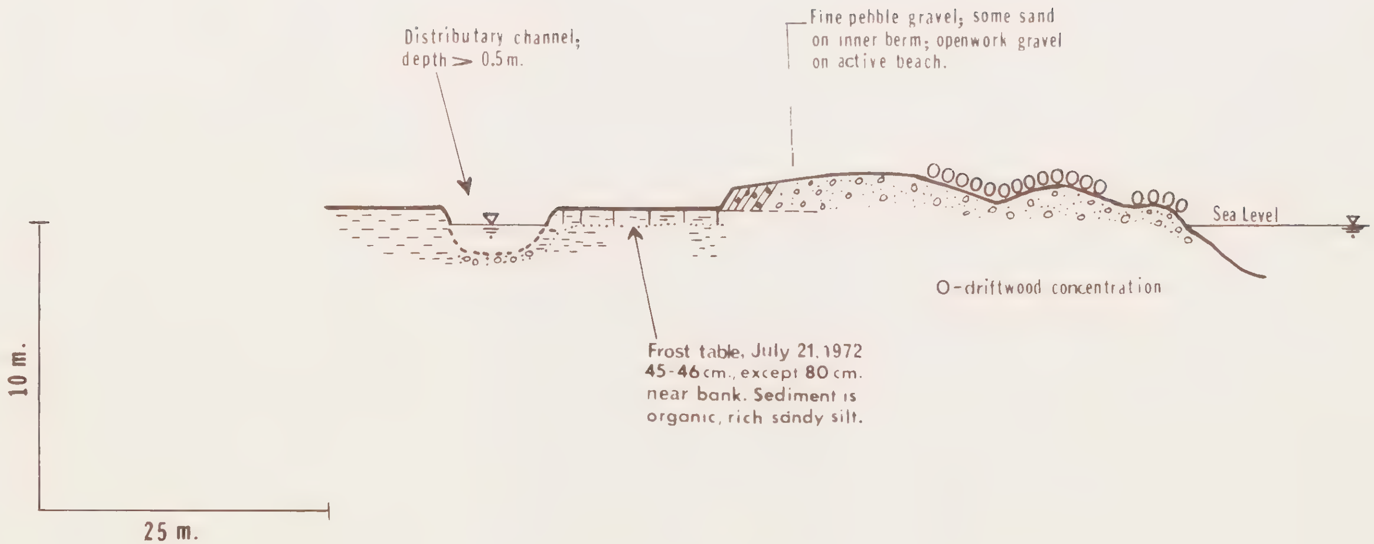



Figure 62. Beach on seaward side of Running River delta.

Figure 63. Beach composed entirely of organic material at seaward edge of Blow River delta. (21 July 1972; GSC 202261 - Y)

Figure 64. Flat surface of Blow River delta, with thermokarst lakes. (21 July 1972; GSC 202261 - Z)

Figure 65. Distributary channel on Blow River delta, looking upstream. (21 July 1972; GSC 202262 - B)

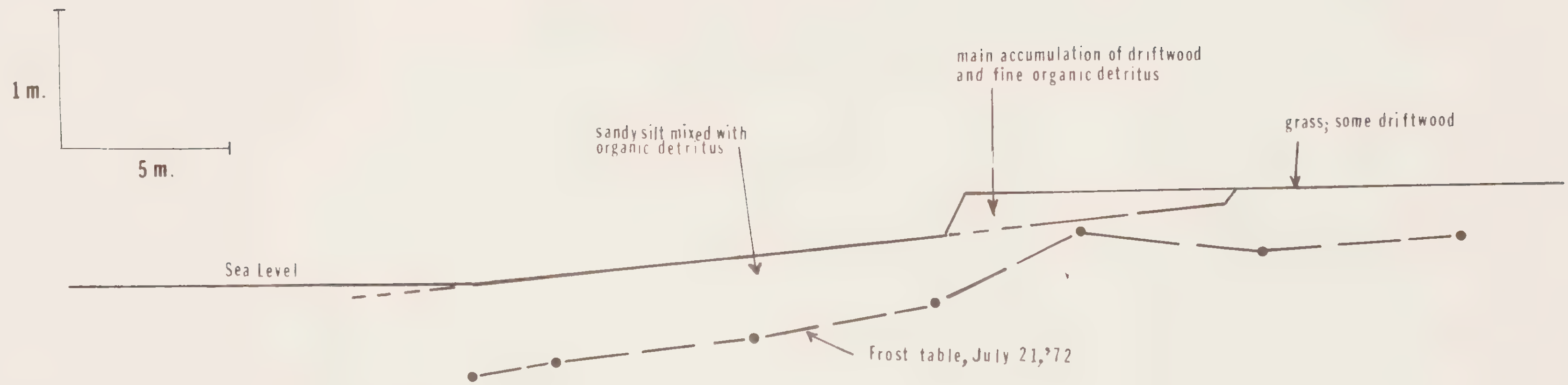



Figure 66. Position of frost table on west side (seaward edge) of Blow River delta, 21 July 1972.

but they seem to be texturally similar to the Babbage system).

## Running River delta

Surface sediments on the Running River delta are texturally similar to those of the Babbage delta. Because the Running River delta (Figure 61) is prograding onto an open coast, waves have reworked the subaerial delta front into a sandy pebble gravel beach. This beach, and the deltaic sediments behind it are shown diagrammatically in Figure 62 along with the position of the frost table.

Movement of sand southeastward past the delta front results in the river outlet channel shifting its location. In 1952 the outlet was located on the southeast side of the delta lobe, but in 1970 and 1972 on the north side of the lobe.

## Blow River delta

The Blow River delta front, being located nearest the mouth of the Mackenzie River and the downstream end of the longshore drift cell, is exposed to large quantities of driftwood. The beach on the northwest side of the delta lobe (Figure 63) is locally composed entirely of driftwood and organic detritus. More generally, however, the beach ridges on the northwest side are composed of fine shingle gravel.

Sediment samples on the delta and farther up-river indicate that the Blow River system is texturally like the Babbage (see Figure 60). The delta surface is flat; frost cracks and scattered thermokarst lakes (Figure 64) indicate the presence of excess ice in the sedimentary sequence. Distributary channels (Figure 65) have banks 0.5 to 1.0 m. high that expose silt rich in organic detritus. The channels are relatively narrow and deep, owing to the cohesive nature of the bank material.

The position of the frost table on 21 July 1972 (Figure 66) was greatly influenced by the presence or absence of an insulating mantle of organic detritus, but generally lay within 60 cm. of the delta surface.

Minor accretion has occurred on the northwest flank of the delta lobe between 1954 and 1970 (Figure 43).

# 7. DISCUSSION

## 7.1. Rivers

This study indicates some of the types of information which can be collected about a river in a very short period of time and some of the inferences which can be drawn from this information. It also indicates the problems which can arise, problems resulting from the superficiality of the approach, from lack of basic knowledge about gravel-bed rivers, and from the singular features of arctic rivers. At the present time, however, few data are available on arctic rivers and almost none on Yukon north slope rivers. Only McCloy's (1970) field work refers directly to a Yukon coast river and his field investigations were of such short duration that processes could only be tentatively indentified.

Dominant discharge estimates can be useful indicators of the sediment movement characteristics of a river system. For maximum benefit, though, they must be tied to a solid framework of systematic hydrologic

data. This framework is not yet avilable for the Yukon north slope. In addition, the reliability of the estimates is dependent upon the ability of the formulas involved to accurately predict river flows. Both this study and that of Church (1972) suggest that available formulas fail to adequately describe gravel rivers. The results of the present work are of some use, however, if only because they are based on field data and do illustrate the inadequacy of some of the purely hydrologic methods of discharge estimation as applied to the Yukon north slope.

The questions of river bed and bank stability are particularly difficult to answer with a short term study. Lateral cutting of gravel bars appears to be a common form of scour but the behavior of channel beds under extremely high flow conditions remains unknown. The presence of frozen ground further complicates any evaluation of the problem.

## 7.2. Coast

Stability of coastal cliffs is related to such factors as exposure to storm waves, protection of the cliffs by onshore on near-shore sediment bodies, the type of material in the coastal cliff, and any irregularity in the ground surface above the cliff (e.g. tundra polygons). Work by Rampton (1970, and in progress) provides critical data regarding type of material and their ice contents that can be used to help evaluate present stability of the cliffs. The 26-year historical record of coastal behaviour displayed on Maps 3, 4, and 5 and on Figures 39 and 43 is also an important input into such an evaluation. However, the possibility exists that the sediment units in the cliff faces twenty years ago have now been worn away and new sediment bodies, that behave differently are now exposed.

Grain-size distribution of materials in eroding coastal cliffs is also closely related to the type of near-shore sediment body that can be maintained by sediment derived from the cliff and distributed by longshore currents. For example, Rampton (oral comm., 1972) suggests that the gravel in Avadlek spit may have been derived largely from gravel bodies that have now been eroded away. The sediments presently exposed in cliffs on the northwest side of Herschel Island contain few stones - insufficient to rebuild Avadlek spit should the spit be removed or damaged. In other cases, however, the spits are healthy and abundant gravel seems to be available to maintain them. The Spring River, for example, regularly delivers sediment to the spits at its mouth, and Fish Creek along with the Firth and Malcolm rivers continually supply Nonaluk spit with sediment.

The near-shore sedimentary processes are also closely related to offshore processes (cf. Shearer, 1972 and in progress; Pelletier and Shearer, 1972). Ice scour of the sea bottom occurs in near-shore areas as well as in depths of 10-50 m. Abrupt depressions that are probably ice-scour marks were observed in 2 m. of water in Phillips Bay. The gouges, seen in profile on the echograms, had no marginal levees, were 30-60 cm. deep with a top width of 2-4 m. Similar gouges were observed in 5 m. of water on profile P7 off Kay Point.

It is important to emphasize that numerical values for coastal change that occurred between 2 or 3 points in time cannot reliably be translated into an annual rate for design purposes. Data are needed first on the magnitude and frequency of the events producing the change. For example, a net retreat of 20 m. in 20 years does not preclude the temporary presence there in the interim of a large accumulation of sediment, or the possibility that the 20 m. was eroded in one particularly bad storm and

that for the rest of the time the coast was stable.

## 8. CONCLUSIONS

### 8.1. Rivers

The main scientific conclusions resulting from the river study are:

1. Channel patterns of Yukon north slope rivers range from full meandering to braided. Wandering reaches are common and, because of their intermediate position between meandering and braided, are difficult to evaluate hydraulically without detailed field measurements;
2. The rivers generally flow in their own alluvium, but they appear to be slowly downcutting, possibly in response either to present-day tectonic uplift or to decreased sediment supply;
3. Estimates of dominant (channel forming) discharges indicate that existing hydraulic formulas do not adequately describe the behavior of gravel rivers. They suggest, as well, that purely hydrologic methods of estimating flood discharges are unreliable, largely because of the absence of relevant unput data;
4. Flow events of sufficient magnitude to cause appreciable bed scour, i.e. flows exceeding dominant discharge, can occur at any time during the open-water season;
5. Suspended load concentrations vary greatly during the open-water period but are directly correlated with discharge and are highest during spring break-up and during summer storm floods. Concentrations approaching 5000 mg./1/. have been measured;
6. Assessment of bed scour is complicated by the influences of bed imbrication, ice jams, spring flow over ice, and frozen ground. Stones in the gravel beds of the channels are imbricated and offer considerably more resistance to erosion than their size would suggest. Because of this, lateral cutting of channel bars and localized erosion on bar surfaces may be the most common forms of scour in Yukon coastal plain rivers. Nothing is known, however, about the behavior of channel beds during extreme flood conditions;
7. Lateral erosion may be locally severe, particularly where fine-grained floodplain sediments are exposed to thermal niching and block slumping. At one such location on the Babbage River bank retreat averaged 2.0 m. over a one-year period. On a larger scale, ground-ice slumps on valley walls expand rapidly (over 10 m. of headwall retreat in a one-year period was measured on one) and provide considerable sediment to the bordering river. Such slumps are not common on the Yukon coastal plain, however. Over the entire coastal plain, airphotographs indicate few areas of rapid channel migration during the last 16 to 20 years.
8. Permafrost has a variety of effects on both river hydrology and channel stability. These include increasing the proportion of surface to total runoff, retarding bank erosion over short time spans, and adding to the relative importance of block slumping in channel migration. Permafrost beneath river beds could have serious implications for development.

## 8.2. Coast

The main scientific conclusions resulting from this coastal study are:

1. Coastal areas that have undergone the most pronounced general retreat in recent years are the area between Komakuk Beach and Alaska, the northwest, northeast, and southeast coast of Herschel Island, and the coast from Kay Point for a distance of 10 km. southeastward;
2. Sediment derived from coastal erosion and sediment delivered to the coast by rivers is dispersed along the coast by well developed systems of longshore currents. Longshore movement of sediment is responsible for hundreds of metres of spit extension between 1952 and 1970. These currents transport sediment to three main sediment sinks in the Yukon coastal zone: (a) between Herschel Island and the mainland, (b) Phillips Bay, and (c) Shoalwater Bay;
3. Ice-push did not exert a major influence on the shore zone in 1972;
4. Silt carried to the coast by rivers is stored in deltas of the Babbage River and Blow River types, whereas clay is carried directly offshore. Silty sediments in the upper parts of these deltaic bodies are rich in excess ice;
5. Frost tables in mid-July, a month after break-up, are only a metre or less beneath the surfaces of gravel spits and intertidal sand bars and beneath the bottoms of deltaic distributary channels that are as deep as 5.8 m.; and
6. Gravels in the shore and near-shore zones contain resistant pebbles and may locally be as thick as 8-9 m. but are probably more generally 4 m. or less in thickness.

# 9. IMPLICATIONS AND RECOMMENDATIONS

## 9.1. Rivers

### 9.1.1. General Scientific

A major objective of the river study was to identity those characteristics of arctic rivers which differ significantly from rivers in more temperate areas. These include:

1. Complete stoppage of flow in the channel during the winter on some rivers;
2. The presence of an impermeable permafrost layer in the uplands and beneath many of the channels, which prevents infiltration and increases the importance of surface runoff;
3. The dominance of thermal niching and block slumping in lateral channel movement, particularly where frozen river-bank sediments are fine grained; and
4. The decrease in frequency, because of the presence of frozen ground, of catastrophic changes in channel morphology.

### 9.1.2. Matters Relevant to Pipeline Activity

1. Rivers of the Yukon coastal plain should provide no serious obstacle to pipeline activity if construction practices take the following factors into account:

(a) Destruction of surface vegetation on the river banks will permit the active layer to thicken. Where river banks contain fine sediments with a high ice content melting, slumping, and major erosion of the river bank could result;
(b) Disturbance of the natural imbrication of stones in the river bed will temporarily reduce the ability of the bed to resist scour;
(c) Construction during the late autumn or winter when flow is low will enable construction to be completed and the channel returned as nearly as possible to its natural form without interference from major flow events. In addition, the downstream effects of construction such as increased suspended load would be minimized because of the low capacity of the flow to move sediment. Migration and spawning schedules of fish will, however, have to be considered; and
(d) A pipeline buried beneath the river bed could create a thermal disturbance by thawing frozen material (hot pipeline) or by freezing unfrozen material (cold pipeline). In either case, local aufeis may develop. This could dislocate the pipe and localize intense river-bed and -bank scour at the pipeline crossing.

2. Most rivers of the Yukon north slope have beds of pebble or cobble gravel. Clasts are generally quartzitic and resistant, although much of the sand and granule fraction in the Babbage River basin is composed of shale. From a geomorphic point of view limited use of river gravel for construction purposes could be considered, keeping in mind: (a) that the major bed-movement events associated with dominant or larger discharges will periodically re-establish the local bed elevation and bar pattern; (b) that removal of gravel at some localities and under some circumstances could increase the rate of bank erosion locally and could adversely affect the spawning and migration of fish; and (c) the possible occurrence of frost beneath the beds of the shallow rivers of the Yukon coastal plain could complicate plans to excavate gravel from the river beds.

## 9.2. Coast

### 9.2.1. General Scientific

In addition to conclusions listed in Section 8 of this report, one finding should be considered further. This is the occurrence below a Babbage delta channel bottom of a probable frost table. The prominent reflector, that appears from probings in shallower areas to be frost, lies only 60 cm. below the channel bottom where water depth is nearly 6 m. (Figure 59, middle). Considering that the ice thickness in winter is of the order of 2 m., a channel 6 m. in depth would not normally be expected to freeze to the bottom. This should result in a substantial talik beneath the channel bottom there. In this case, however, the Babbage River freezes to the bottom farther upstream and Phillips Bay, farther downstream, is frozen to the bottom in winter. Thus there may be little or no winter flow in the deep channel. There would seem to be five alternative explanations for this feature, all of which could be tested by winter drilling on the site: (a) the prominent reflector is not the frost table; (b) water in this

stagnant pool freezes to the bottom; (c) sedimentation as flow wanes during freeze-up builds up the channel bottom to a point where the water can freeze to the bottom (in winter) and can freeze the sediment fill. In spring, the channel is re-eroded to a depth in adjustment with spring and summer discharges; (d) there has recently been a sudden, and unlikely, shift in the thalweg position; or (e) water temperatures in such unfrozen pockets, particularly where the water is brackish, decreases in winter to lower than $0^{o}C$, resulting in the freezing of fresh pore water in sediments beneath the channel while unfrozen water remains in the channel. With river discharge being high in the spring and summer but low in the fall, it is quite possible that pore-water in the sediment would be fresh whereas upstream migration of the salt-water wedge in the autumn would bring brackish water into the delta channels. The salinity of this water would be further increased by winter freezing of the water surface.

If the prominent reflector is indeed the frost table, then sub-bottom profiling may prove to be a useful tool in determining a maximum value for scour depth during spring floods of some arctic rivers.

### 9.2.2. Matters Relevant to Pipeline Activity

1. Insofar as the coastal zone is used for staging areas or for shore installations, the dynamics of the shore area must be taken into account. Either coastal retreat or accumulation could jeopardize the success of such an operation. Any interruption of the long-shore drift pattern will have feedback both up and down the coast that will disturb the natural balance. This is not to say that the effects would necessarily be harmful, but they should be anticipated.
2. The Babbage, Blow and Running river deltas have a high silt content and their sediments are rich in excess ice. Thermal disturbance of these areas could lead to considerable thaw consolidation. In addition to this, thermokarst lakes on flat deltaic plains tend to be favoured by wildfowl for nesting purposes. In 1972 the Babbage delta was a major nesting area for whistling swans.
3. Thermokarst lakes on the extensive flat surface of the Babbage and Blow river deltas lie below the level of storm surges along the coast. They are also important nesting areas. Oil from a spill could be spread into these lakes during a storm tide, with serious ecological consequences.
4. In the event of oil reaching the coast, some potential may exist to make use of near-shore current patterns to predict its spread. Lagoons behind spits and offshore barrier islands are common along parts of the Yukon coast. These could prove to be useful natural containers for spilled oil if it is possible to divert oil into them. Shore storage of large amounts of oil could also be located behind such lagoons.
5. Active gravel and sand bodies in the shore and near-shore area could be useful sources of construction material. If the alternative is establishing an overland route for several kilometres to a pit a "fossil" gravel body at some distance from the shore and thereby leave permanent scars on the landscape, it would seem preferable both economically and environmentally to remove gravel from a nearby "living" environment that can repair the damage done. Because many, but possibly not all, spits are important

nesting areas, because perforating a spit could set up an instability that could destroy it, and because existing gravel supply in longshore currents is insufficient to repair certain spits and beaches, selection of a locality for a pitting operation would have to be made very carefully and only after detailed study of a particular proposal. However, such pitting operations might well create less disturbance than certain natural calamities, such as storm tides, from which the environment manages to recover.

## 10. NEEDS FOR FURTHER STUDY

This has been a reconnaissance-level study carried out in a very short time in the field. Much more detailed studies will have to be carried out when firm requirements make it possible to specify particular sites of interest.

It is possible now, however, to identify important gaps in the data, some of which could be plugged by short-term studies:

### (a) Hydrologic Regime of North Slope Rivers.

At present, of all the Yukon north slope rivers, only the Firth is systematically gauged, and it only since the spring of 1972. Although the establishment of more gauging stations - particularly on the Babbage and Blow Rivers - would be extremely useful, the expense of such installations could be prohibitive, expecially given the limited short-term value of the data collected. Temporary gauging stations set up only to monitor several summer rainstorm floods would be almost as useful. They would provide knowledge of the rivers' reactions to precipitation events and would enable more reasonable extrapolation to be made, using unit hydrograph theory, to the effect of extreme storm rainfalls.

### (b) Thermal Regime of River Beds

In order to understand more fully the risks involved to river installations and the problems that may arise during their construction, it is important to understand the thermal regime of the river beds. Information is required on the existence and extent of taliks, on whether there is a winter flow of water either in or beneath the river channels, and on the temperature profiles beneath the channels. The existence and location of permafrost beneath the channels would be an important construction consideration. Such information would be largely obtained from a drilling project and should be carried out in middle to late winter.

### (c) Monitoring of Geomorphic Change

Photogrammetric measurements of coastal change should be completed between the Alaska border and the mouth of the Firth River. This should be possible when new aerial photographs become available for that part of the coast, as the only useful photographs currently available date from the early 1950's.

Periodic air photography (e.g. every two years) of the coast would permit a better appraisal of the magnitude/frequency balance of processes effecting geomorphic change. Detailed instrumentation at particular sites can provide useful information on processes, but regional and long-term

appreciation of geomorphic change is best served by photogrammetric measurements.

Efforts should be made to visit the field during or immediately after very major storms because it is then that the most dramatic geomorphic changes occur. In this respect, the report by the Canadian Department of Public Works (1971) has been most useful.

(d) Use of "Living" Environments as Sources of Aggregate

Mention has been made in this report of the possible desirability of obtaining sand and gravel for construction purposes from active river beds and from coastal beaches, bars and spits. It must be emphasized that this possibility is discussed here only from a sedimentological point of view. In many areas the biologic or other ecologic consequences of such excavations may make disturbance of the natural environment completely unjustified. Even in the limited context considered here, it is essential to obtain, for each site, sufficient knowledge of rates of sediment transport and locations of adequate reserves of sand and pebbles so that natural repair of the environmental damage is assured without unduly stressing nearby environments. Only with such knowledge should applications to mine specified volumes at specified sites be sanctioned.

The possibility has been mentioned, for example, that Avadlek spit (Herschel Island) contains gravel largely derived from an older gravel body that has long since been eroded by the general recession of the nearby coast. The mining of Avadlek spit could, therefore, result in damage that would never be naturally repaired. If this particular spit were to be breached or destroyed the entire pattern of longshore currents and sediment dispersal for this part of the Yukon coast could be seriously modified.

A summer field program would be necessary to throughly and systematically study the distribution, thickness, and stratigraphy of near-shore sediments, current patterns, and bathymetry from a depth of 10 to 15 m. up to the highest storm tide level in order to gain sufficient knowledge of sediment movement along the Yukon coast. This would also generate specific information required to assess the hazards of a major oil spill there and the best methods of coping with it.

## 11. REFERENCES


Abrahamsson, K.V. 1966. Arctic environmental changes; Arctic Inst. of North Amer. Res. Paper 39, 79p.

Allen, J.R.L. 1965. A review of the origin and characteristics of recent alluvial sediments. Sedimentology, v. 5, no. 2, pp. 89-191.

Am. Soc. Civ. Eng., Task Committee for Preparation of Sedimentation Manual, Vito A. Vanoni, Chmn. 1971. Sedimentation engineering, Chapter II: Sediment transportation mechanics: Q. Genetic classification of valley sediment deposits. Am. Soc. Civ. Eng., J. Hydraulics Div., v. 97, no. HY1, Proc. Paper 7815, pp. 43-53.

Arnborg, L., H.J. Walker, and J. Peippo. 1966. Water discharge in the Colville River, 1962. Geog. Ann., v. 48A, no. 4, pp. 195-210.

____________ 1967. Suspended load in the Colville River, Alaska, 1962, Geog. Annaler, 49A (2-4), pp. 131-144.

Bostock, H.S. 1969. Physiographic subdivisions of Canada; in R.J.W. Douglas (ed.), Geology and economic minerals of Canada; Econ. Geol. Rept. 1, Geol. Surv. Can., pp. 10-30.

____________ 1970. Physiographic regions of Canada. Geol. Surv. Can., Map 1254A.

Bray, D.I. and R. Kellerhals. 1972. Numeric coding of the major geomorphic and physoigraphic characteristics of a river reach. Research Council of Alberta and Dept. of Civil Eng., Univ. of Alberta. 26 p.

Brewer, M.C. 1958. Some results of geothermal investigations of permafrost in northern Alaska. Am. Geophys. Union, Trans., v. 39, no. 1, pp. 19-26.

Bryson, R.A. 1966. Air masses, streamlines, and the boreal forest. Geog. Bull., v. 8, no. 3, pp. 228-269.

Canada. Department of Public Works. 1971. Herschel Island - Feasibility of a marine terminal; unpub. rept., 141p.; and, Beaufort Sea Storm - Investigation of effects in the Mackenzie delta region; unpub. rept., 23p.

Canada. Department of Transport. 1967. Ice summary and analysis, Canadian arctic, 1964. Ottawa, Queen's Printer, 79 p.

____________ 1971. Ice Summary and analysis, Canadian arctic, 1968. Ottawa, Queen's Printer, 77 p.

Carston, C.W. 1965. The relation of free meander geometry to stream discharge and its geomorphic implications. Am. J. Sci., v. 263, no. 10, pp. 864-885.

Chow, V.T. 1964. Runoff. Section 14 in: V.T. Chow (ed.). Handbook of Applied Hydrology. New York: McGraw-Hill.

Church, M.A.. 1971. Reconnaissance of hydrology and fluvial characteristics of rivers in northern Alaska and northern Yukon Territory. Rept. prepared for Mackenzie Valley Pipeline Research, Ltd, 197 p.

____________ 1972. Baffin Island sandurs: A study of Arctic flucial processes. Geol. Surv. Can., Bull.216, 208 p.

Dalrymple, T. 1964. Hydrology of Flow Control. Section 25-I in: V.T. Chow (ed.). Handbook of Applied Hydrology. New York: McGraw-Hill.

Dingman, S.L. 1966. Hydrologic studies of the Glenn Creek drainage basin near Fairbanks, Alaska. U.S. Army, Cold Regions Res. and Eng. Lab. Spec. Rep. 86, 30 p.

Duguid, J.O. 1971. Thin gravel deposits on wave-eroded cliffs near Barrow, Alaska. Arctic, v.24, No.4, pp. 304-306.

Hare, F.K. 1969. The atmospheric circulation and arctic meteorology. Arctic, v. 22, no. 3, pp. 185-194.

Henderson, F.M. 1966. Open channel flow. New York: MacMillan. 522 p.

Hughes, O.L. 1972. Surficial geology of northern Yukon Territory and northwestern District of Mackenzie, Northwest Territories; Geol. Surv. Can., Paper 69-36, 11p.

Kellerhals, R. 1967. Stable channels with gravel-paved beds. Am. Soc. Civ. Eng., J.Waterways and Harbours Div., v. 93, no. WW1, Proc. Paper 5091, pp. 63-84

Kellerhals, R. and D.I. Bray. 1971. Sampling procedures for coarse fluvial sediments. Am. Soc. Civ. Eng., J. Hydraulics Div., v. 97, no. HY8, Proc. Paper 8279, pp. 1165-1180.

Lane, E.W. and E.J. Carlson. 1953. Some factors affecting the stability of canals constructed in coarse granular materials. Minn. Int. Hydraulics Convention, Proc., pp. 37-48.

Limerinos. J.T. 1970. Determination of the Manning coefficient from measured bed roughness in natural channels. U.S. Geol. Surv., Water Supply Paper 1898-B, 47 p.

Mackay, J.R. 1963. Notes on the shoreline recession along the coast of the Yukon Territory. Arctic, v.16, pp. 195-197.

McCloy, J.M. 1970. Hydrometeorological relationships and their effects on the levees of a small arctic delta. Geog. Annaler, v.52A, no.3-4, p.p. 223-241.

Miller, V.C. 1953. A quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee. Project NR389-042, Tech. Rept. 3; Columbia University, Department of Geology; Office of Naval Research, Geography Branch, New York.

Mollard, J.D. 1973. Air photo interpretation of fluvial features. Paper presented at the 9th Can. Hydrology Symp., Edmonton, Alta, 17 p.

Neill, C.R. 1967. Mean-velocity criterion for scour of coarse uniform bed-material.12th Congress, Int. Assoc. Hydraulic Res., Proc. pp. 46-54.

Norris, D.K., R.A. Price, and E.W. Mountjoy. 1963. Geology, northern Yukon Territory and northwestern District of Mackenzie. Geol. Surv. Can., Map 10-1963.

O'Neill, J.J. 1924. Geology of the Arctic Coast of Canada, west of the Kent Peninsula. Rept. of Canadian Arctic Expedition 1913-1918, II, Geology and Geography, Pt A.

Pelletier, B.R., and Shearer, J.M. 1972. Sea bottom scouring in the Beaufort Sea of the Arctic Ocean. Proc. 24th Int. Geol. Cong., Sec. 8,p. 251-261.

Rampton, V.N. 1970. Surficial geology maps of Demarcation Point (117C), Herschel Island (117D), Blow River (117A), and Aklavik West (107B). Geol. Surv. Can. Open file 21.

__________________________. (in press). Quaternary geology - Mackenzie - Beaufort region. Rept. prepared for Environmental-Social Program, Northern Pipelines.

Reed, R.J. and B.A. Kunkel. 1960. The Arctic circulation in summer. J. Meteorology, v. 17, no. 5, pp. 489-506.

Shearer, J.M. 1972. Thickness of Recent (post-glacial?) mud in Beaufort Sea. Geol. Surv. Can., Open File 126.

Solomon, S.I., Denouvilliez, T.P., Cadou, C., and Chart, E.J. 1968. The use of a square-grid system for computer estimation of precipitation, temperature, and runoff in a sparsely gauged area. Water Resources Research, v.4, no.5 pp. 919-930.

Solomon, S.I. and Qureshy, A.S. 1972. Hydrologic data banks - present status and potential. Engineering Journal, v.55, pp. 9-14.

Strahler, A.N. 1953. Hypsometric (area-altitude) analysis of erosional topography. Bull. Geol. Soc. Ammer., v.63, pp. 1117-1142.

Walker, H.J. and L. Arnborg. 1965. Permafrost and ice-wedge effect on riverbank erosion. Permafrost Int. Conference, 11-15 Nov 1963, Lafayette, Indiana, Proc. Nat. Acad. Sci. -Nat. Res. Council (U.S.) Pub. No. 1287, pp. 164-171.

Walker, H.J. and J.M. McCloy. 1969. Morphologic change in two Arctic deltas. Arctic Inst. North Amer., Research Paper 49, 91 p.

Wolman, M.G. and L.B. Leopold. 1957. River flood plains: Some observations on their formation. U.S. Geol. Surv., Prof. Paper 282-C, pp. 87-109.

Zenkovich, V.P. 1967. Processes of coastal development. London: Oliver and Boyd. 738 p.

## 12. NOTATIONS AND ABBREVIATIONS

| | |
|---|---|
| A | cross-sectional area |
| $C_s$ | concentration of suspended solids |
| $C_c$ | concentration of colloidal and dissolved solids |
| $^oC$ | degrees Centrigrade |
| D | particle size (based on intermediate axis length) |
| $D_{84}$, $D_{90}$ | particle size for which 84 or 90 per cent by weight is finer |
| $D_m$ | Folk mean |
| $D_{so}$ | Inclusive graphic standard (Folk) |
| $D_{sk}$ | Inclusive graphic skewness (Folk) |
| $D_k$ | Graphic kurtosis (Folk) |
| $\bar{d}$ | mean flow depth |
| Fr | Froude No. |
| g | acceleration due to gravity |
| $L_m$ | meander wavelength |
| n | Manning roughness coefficient |
| P | wetted perimeter |
| Q | discharge |
| $Q_b$ | bankfull discharge |
| $Q_s$ | sediment discharge |
| R | hydraulic radius |
| S | energy slope |
| $S_m$ | map slope |
| $S_v$ | valley-plain slope (measured in field) |
| $S_w$ | water-surface slope |
| $V_m$, $\bar{V}$ | mean flow velocity |
| $W_s$ | water surface width |

| | |
|---|---|
| $\rho$ | mass density of water |
| $\rho_s$ | mass density of sediment grains |

Abbreviations used in the text:

| | |
|---|---|
| ASL | above sea level |
| cm. | centimetres |
| kg. | kilograms |
| KHz. | kilohertz |
| km. | kilometres |
| l. | litre |
| log. | logarithm to base 10 |
| m. | metres |
| mg. | milligrams |
| mm. | millimetres |
| PPM. | parts per million 1 PPM ≈ mg/l |
| sec. | second |
| μ | micromillimetres |

NOTE: All bankfull calculations in Appendix A have subscript "d", for dominant, added.

# 13. APPENDIX: HYDRAULIC, SEDIMENTOLOGIC, AND GEOMORPHIC DATA FOR EACH RIVER REACH STUDIED.

Data for following river reaches are presented, in the order listed (see map no. 1 for location):

| | | | |
|---|---|---|---|
| Figures | M1 | - | Malcolm River, Reach M1 |
| | F1 | - | Firth River, Reach F1 |
| | F2 | - | Firth River, Reach F2 |
| | F(WSC) | - | Firth River, Reach WSC (Water Survey of Canada Gauging Site) |
| | B1 | - | Babbage River, Reach B1 |
| | B2 | - | Babbage River, Reach B2 |
| | B3 | - | Babbage River, Reach B3 |
| | B4 | - | Babbage River, Reach B4 |
| | B5 | - | Babbage River, Reach B5 |
| | RU1 | - | Running River, Reach RU1 |
| | BL1 | - | Blow River, Reach BL1 |
| | BL2 | - | Blow River, Reach BL2 |
| | BL3 | - | Blow River, Reach BL3 |
| | BL4 | - | Blow River, Reach BL4 |
| | BL5 | - | Blow River, Reach BL5 |
| | R1 | - | Rapid Creek, Reach R1 |
| | BF1 | - | Big Fish River, Reach BF1 |

For each river study reach, some or all of the following data are presented in the order listed:

1. air photograph of reach
2. surveyed cross-sections
3. flood-plain, valley, and water slopes
4. grain-size data
5. field photographs of reach
6. hydraulic data

Malcolm River, reach M1

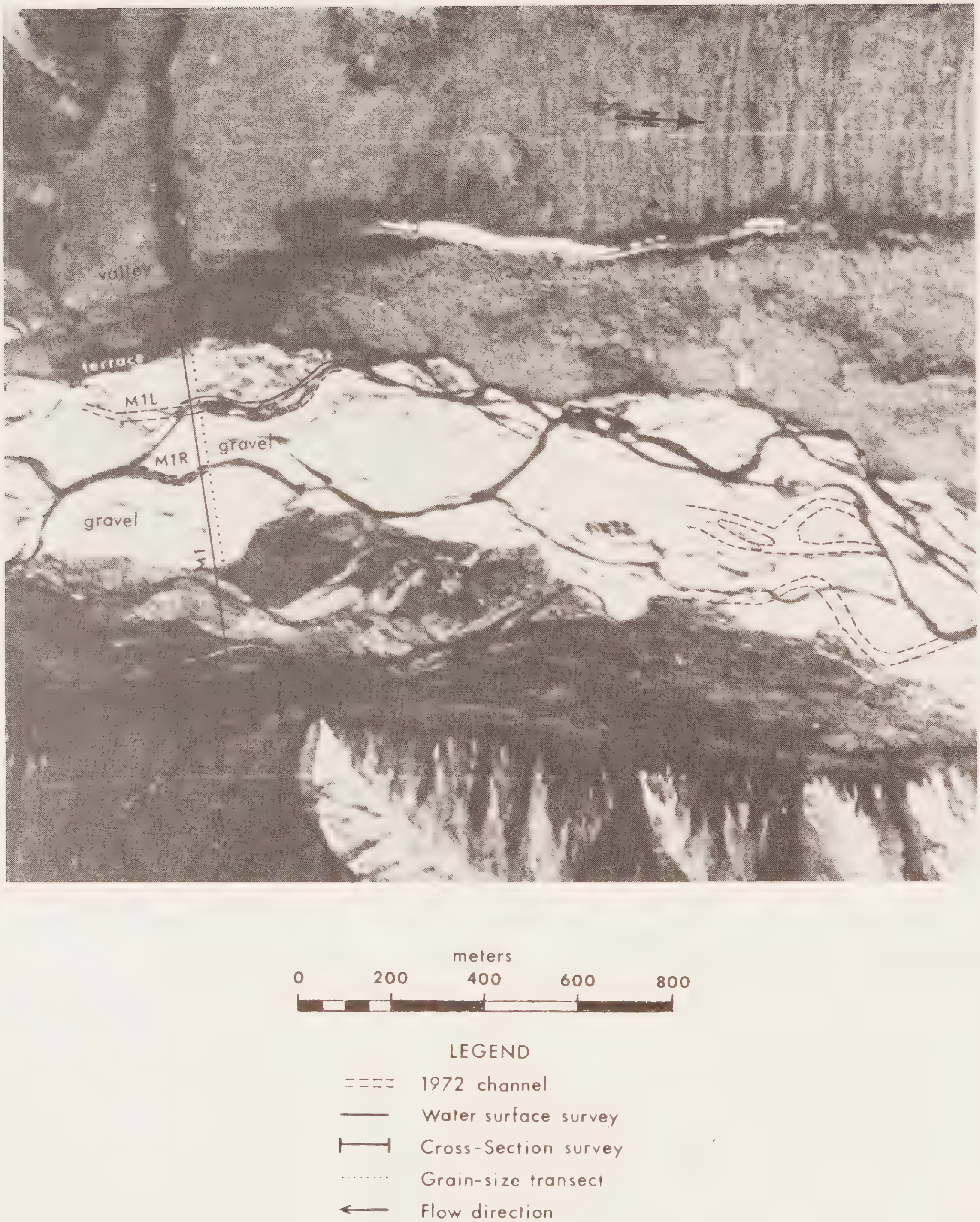



Figure M1:1. Malcolm River, Reach M1 (Photo A14361-83; 1954).

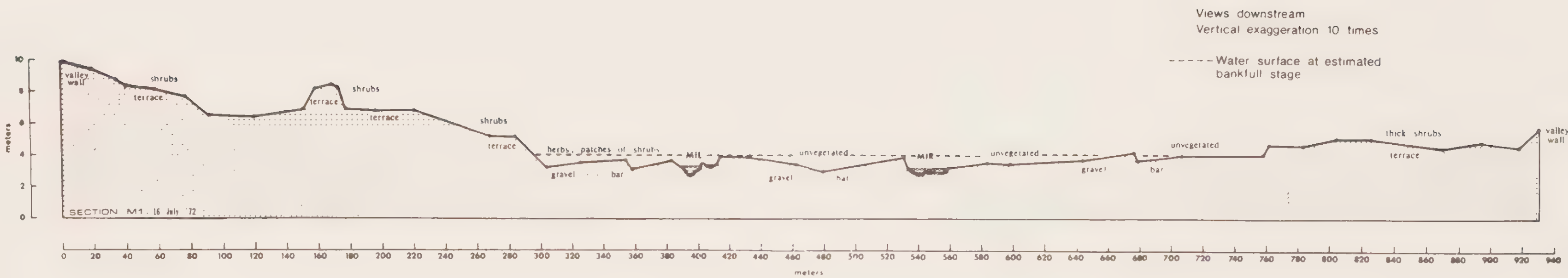



Figure M1:2 Cross-section, reach M1

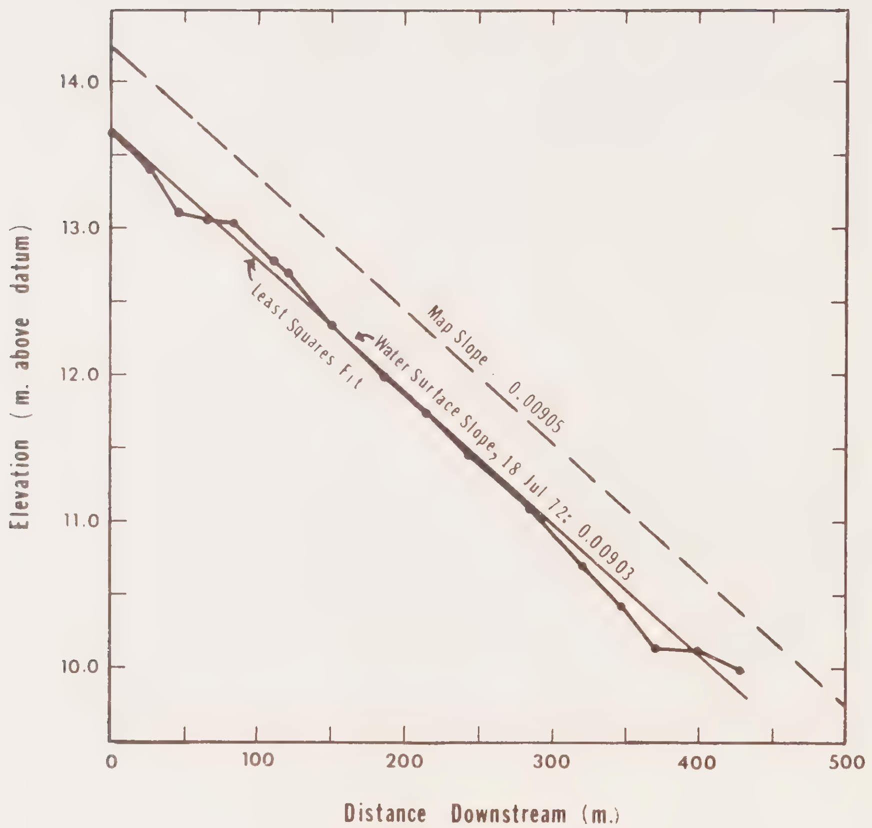
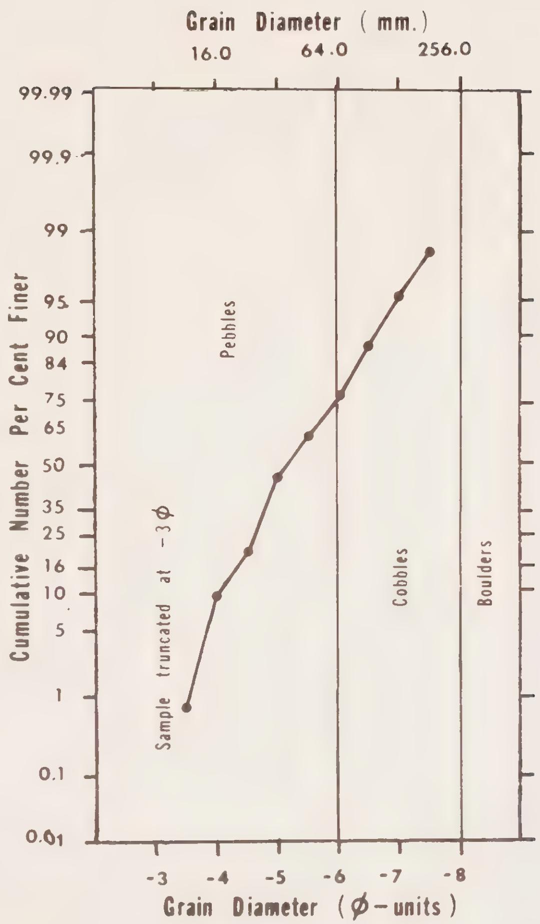



Figure M1:3 Water surface and map slopes, reach M1.




CHANNEL BAR, COARSE FRACTION ( >8 mm.),
GRID SAMPLING

Figure M1:4 Grain-size of surface fluvial sediment, reach M1.

Figure M1:5 View upstream along reach M1. (16 July 1972; GSC 202262-N).

(see also Figure 16 in text)

Yukon North Slope Rivers - Hydraulic Data

Reach: Malcolm River, M1 — Date: 16 Jul 72

a. Grain-size Statistics:

| | mm. | $\phi$ |
|---|---|---|
| $D_m$ | 38.9 | -5.28 |
| $D_{So}$ | | 0.945 (moderate) |
| $D_{Sk}$ | | 0.186 |
| $D_K$ | | 0.941 |

b. Field Hydraulic Data: mean of 1 cross-sections

| Channel No. | M1L[2] | M1R[3] | Total |
|---|---|---|---|
| Q (m.$^3$/sec.) | 6.20 | 6.10 | 12.3 |
| $\bar{v}$ (m./sec.)[1] | 1.55 | 0.875 | |
| Fr | 0.865 | 0.536 | |
| $W_s$ (m.) | 12.2 | 25.6 | |
| P (m.) | 12.9 | 26.1 | |
| $\bar{d}$ (m.) | 0.328 | 0.272 | |
| R (m.) | 0.311 | 0.267 | |
| A (m.$^2$) | 4.00 | 6.97 | |
| $S_w$ | 0.00903 | - | |
| $c_s$ (mg./l.) | - | - | |
| $c_c$ (mg./l.) | - | - | |
| T (°C) | - | - | |

c. Channel Geometry at Estimated Bankfull Stage: mean of 1 cross-sections

| Channel No. | 1 | 2 | 3 |
|---|---|---|---|
| $W_{sd}$ (m.) | 118 | 100 | 128 |
| $P_d$ (m.) | 119 | 101 | 129 |
| $\bar{d}_d$ (m.) | 0.525 | 0.500 | 0.517 |
| $R_d$ (m.) | 0.521 | 0.495 | 0.513 |
| $A_d$ (m.) | 62.0 | 50.0 | 66.2 |
| $S_V$ | - | | |
| $S_M$ | 0.00905 | | |

[1] Based on float velocity data

[2] L = left channel

[3] R = right channel

Firth River, reach F1


Figure F1:1. Firth River, Reach F1 (Photo A21925-88; 1970).

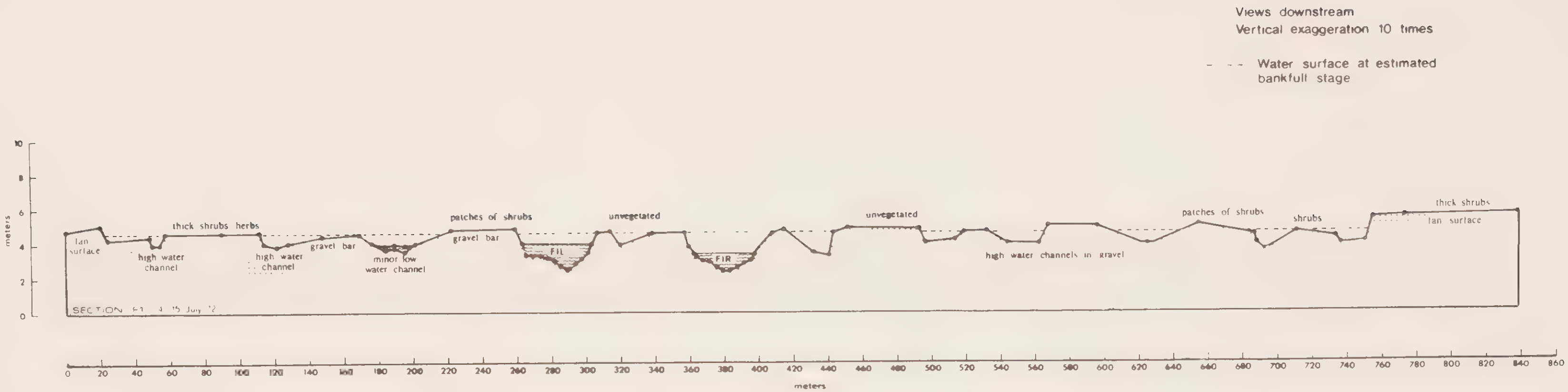



Figure F1:2 Cross-section, reach F1

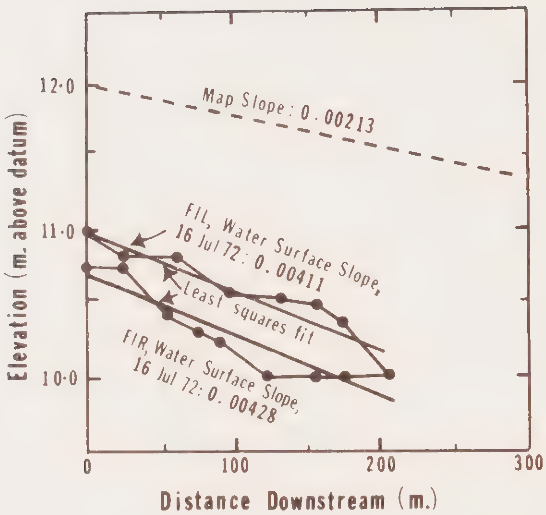



Figure F1:3 Water surface and map slopes, reach F1.

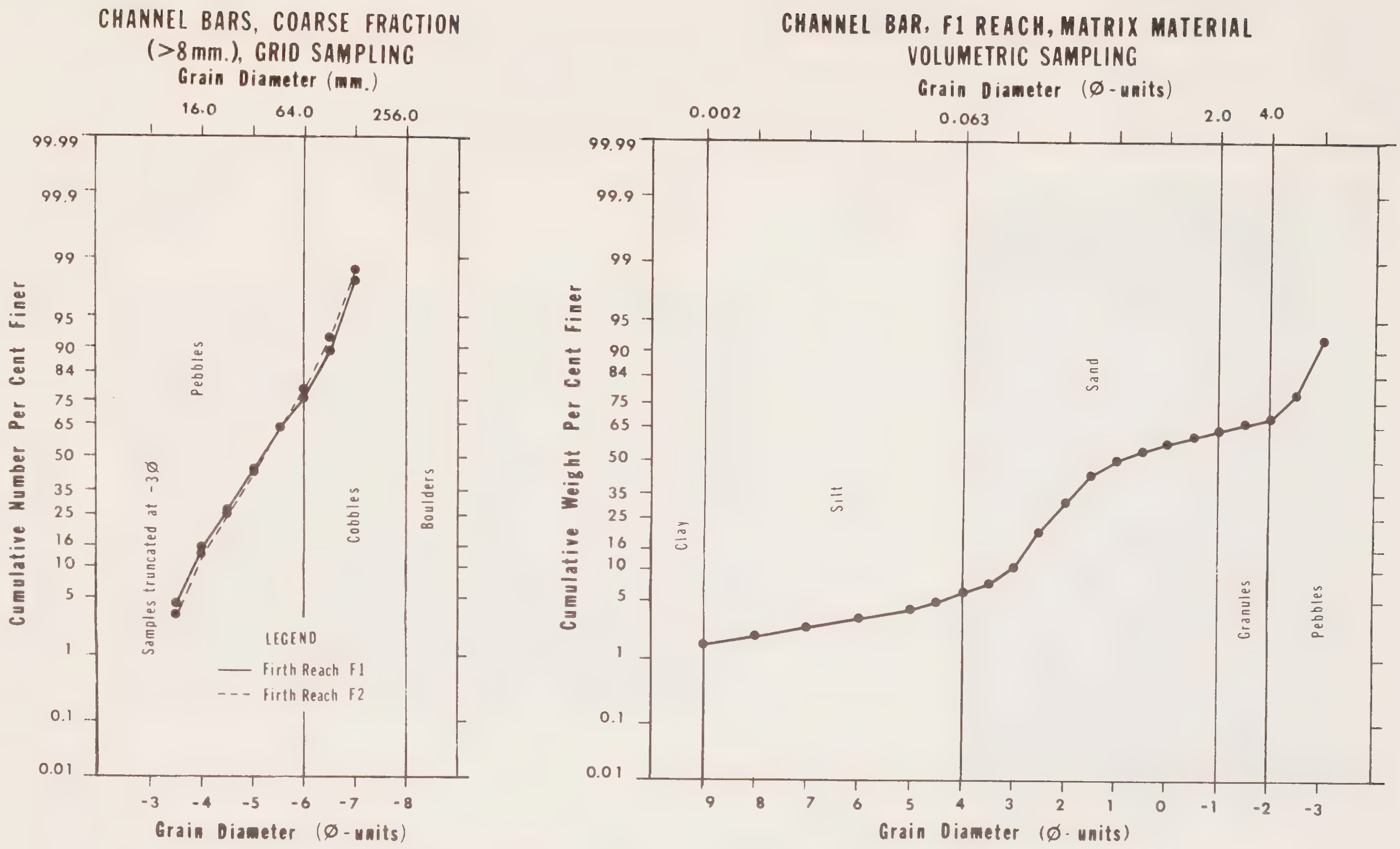



Figure F1:4 Grain-size of surface fluvial sediment, reaches F1 and F2.

Figure F1:5A Reach F1, flow right to left; terraces in middle distance record recent degradation. (17 July 1972; GSC 202261-J).

Figure F1:5B Painted line across gravel bar, reach F1, flow left right
(16 July 1972; GSC 202262-K).

(see also Figures 4 and 27 in text)

Yukon North Slope Rivers - Hydraulic Data

Reach: Firth River, F1 Date: 15 Jul 72

a. Grain-size Statistics:

| | mm. | ϕ |
|---|---|---|
| $D_m$ | 36.8 | -5.20 |
| $D_{So}$ | | 1.04 (poor) |
| $D_{Sk}$ | | -0.00769 |
| $D_K$ | | 0.859 |

b. Field Hydraulic Data: mean of 1 cross-sections

| Channel No. | F1L[1] | F1R[2] | Total |
|---|---|---|---|
| Q ($m.^3$/sec.) | 43.2 | 14.6 | 57.8 |
| $\bar{v}$ (m./sec.) | 1.14 | 0.699 | |
| Fr | 0.375 | 0.290 | |
| $W_s$ (m.) | 40.5 | 35.5 | |
| P (m.) | 42.4 | 36.7 | |
| $\bar{d}$ (m.) | 0.937 | 0.590 | |
| R (m.) | 0.896 | 0.571 | |
| A ($m.^2$) | 38.0 | 21.0 | |
| $S_w$ | 0.00411 | 0.00428 | |
| $c_s$ (mg./l.) | 27 | 8 | |
| $c_c$ (mg./l.) | 146 | 168 | |
| T (°C) | 15.2 | 15.0 | |

c. Channel Geometry at Estimated Bankfull Stage: mean of 1 cross-sections

| Channel No. | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $W_{sd}$ (m.) | 35.0 | 48.0 | 48.0 | 46.0 | 23.0 |
| $P_d$ (m.) | 35.6 | 48.8 | 48.8 | 48.8 | 23.6 |
| $\bar{d}_d$ (m.) | 0.309 | 0.383 | 0.421 | 1.38 | 0.313 |
| $R_d$ (m.) | 0.303 | 0.377 | 0.414 | 1.30 | 0.305 |
| $A_d$ (m.) | 10.8 | 18.4 | 20.2 | 63.6 | 7.20 |
| $S_V$ | - | | | | |
| $S_M$ | 0.00213 | | | | |

Hydraulic Data (cont.) Reach: F1

c. Channel Geometry at Estimated Bankfull Stage: mean of 1 cross-sections

| Channel No. | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|
| $W_{sd}$ (m.) | 51.0 | 26.0 | 24.0 | 31.0 | 40.0 | 24.0 | 32.5 |
| $P_d$ (m.) | 53.7 | 27.5 | 24.8 | 32.1 | 40.7 | 25.2 | 33.4 |
| $\bar{d}_d$ (m.) | 1.35 | 0.746 | 0.417 | 0.529 | 0.370 | 0.608 | 0.443 |
| $R_d$ (m.) | 1.28 | 0.706 | 0.403 | 0.512 | 0.363 | 0.579 | 0.431 |
| $A_d$ (m.) | 68.8 | 19.4 | 10.0 | 16.4 | 14.8 | 14.6 | 14.4 |
| $S_y$ | | | | | | | |
| $S_M$ | | | | | | | |

[1] L = left channel

[2] R = right channel

Firth River, reach F2

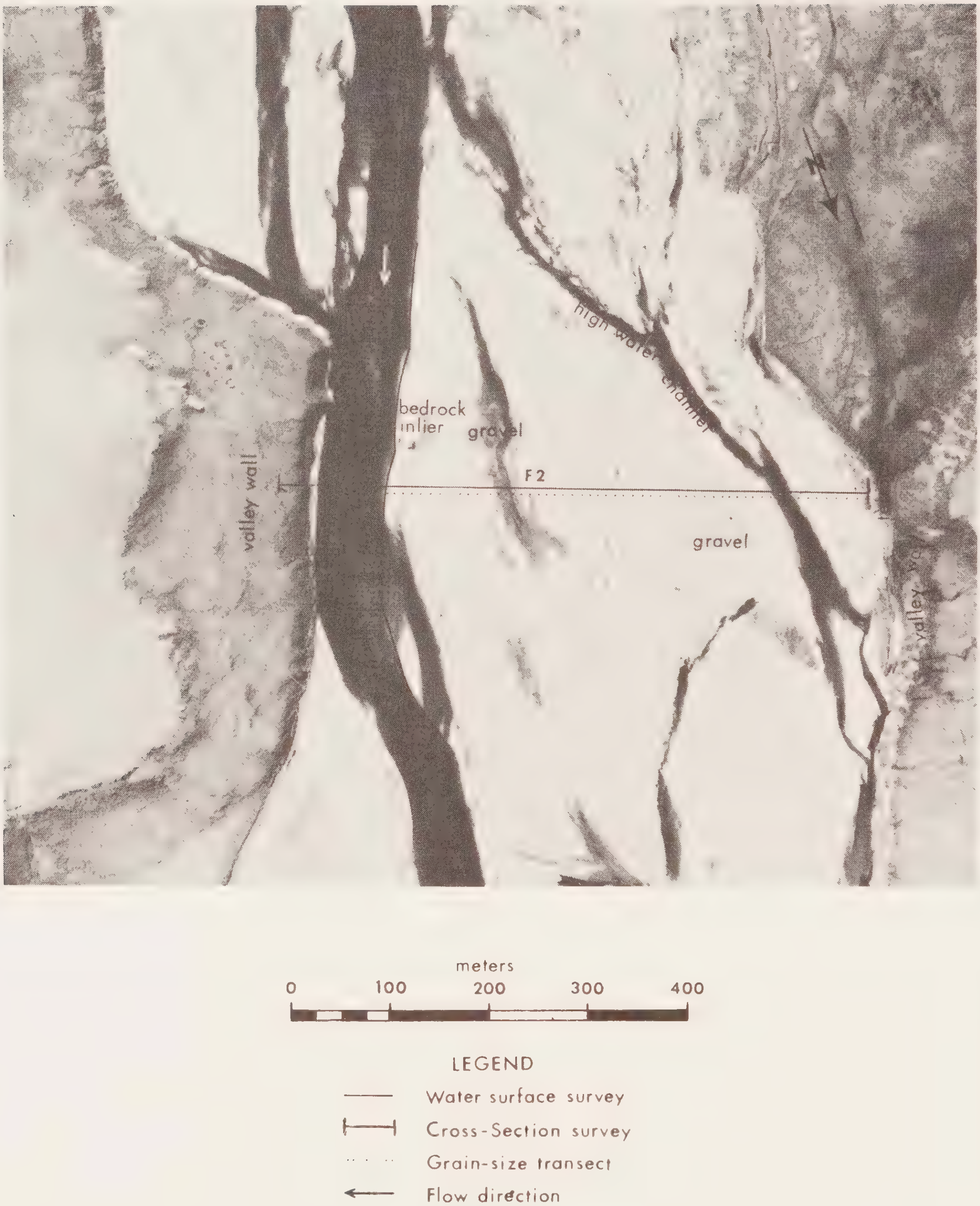



Figure F2:1. Firth River, Reach F2 (Photo A21921-20; 1970).

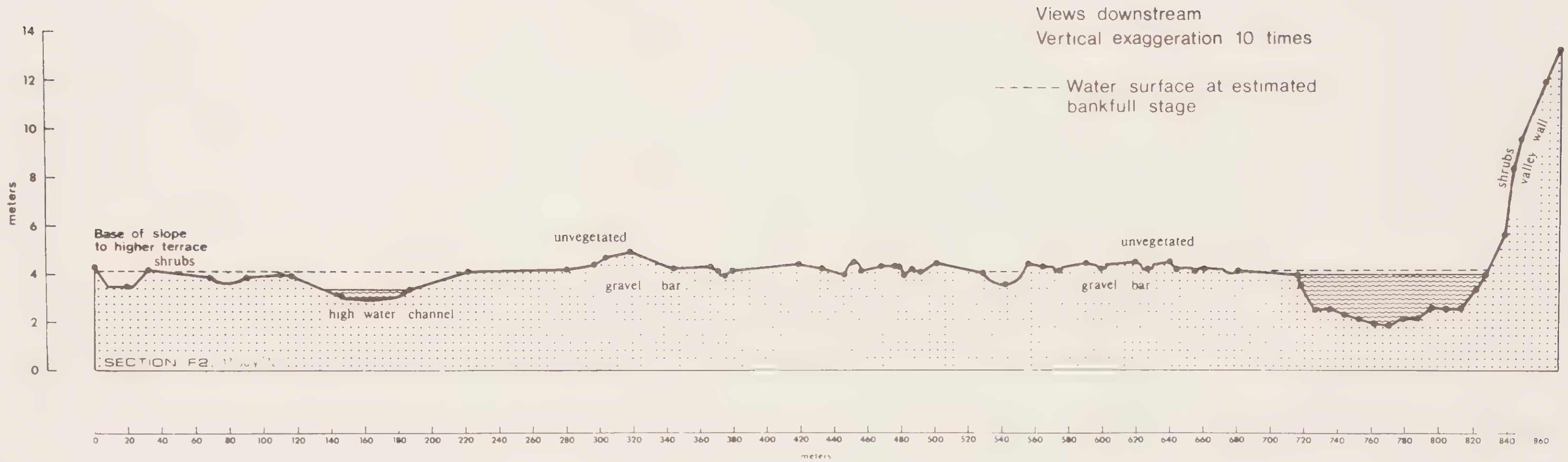



Figure F2:2 Cross-section, reach F2

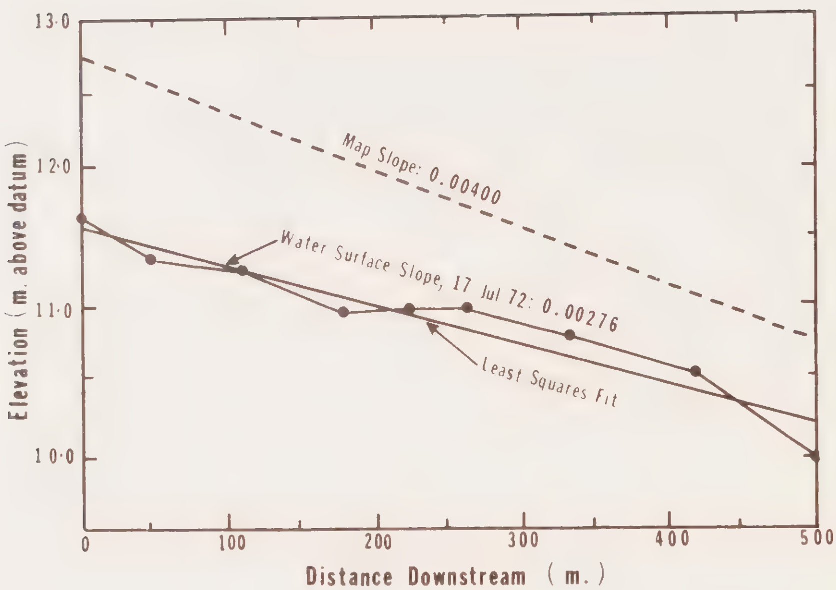



Figure F2:3 Water surface and map slopes, reach F2.

NOTE: See Figure F1:4 for grain-size of surface fluvial sediment, reach F2.

Figure F2:5 Reach F2, looking eastward acorss Firth River valley toward prominent hill (Engigstciak); flow right to left. Dark object out in active river plain is a bedrock outcrop. (17 July 1972; GSC 202262-Q).

## Yukon North Slope Rivers - Hydraulic Data

Reach: Firth River, F2 | Date: 17 Jul 72

**a. Grain-size Statistics:**

| | mm. | $\phi$ |
|---|---|---|
| $D_m$ | 36.3 | -5.18 |
| $D_{So}$ | | 0.967 (moderate) |
| $D_{Sk}$ | | -0.0122 |
| $D_K$ | | 0.878 |

**b. Field Hydraulic Data:** mean of 1 cross-sections

| Channel No. | |
|---|---|
| Q (m.$^3$/sec.) | 197 |
| $\bar{v}$ (m./sec.) | 1.68 |
| Fr | 0.433 |
| $W_s$ (m.) | 77.0 |
| P (m.) | 80.0 |
| $\bar{d}$ (m.) | 1.52 |
| R (m.) | 1.47 |
| A (m.$^2$) | 117 |
| $S_w$ | 0.00276 |
| $c_s$ (mg./l.) | 4820 |
| $c_c$ (mg./l.) | 134 |
| T ($^o$C) | 12.3 |

**c. Channel Geometry at Estimated Bankfull Stage:** mean of 1 cross-sections

| Channel No. | 1 | 2 |
|---|---|---|
| $W_{sd}$ (m.) | 118 | 83.0 |
| $P_d$ (m.) | 119 | 86.2 |
| $\bar{d}_d$ (m.) | 0.502 | 1.61 |
| $R_d$ (m.) | 0.497 | 1.55 |
| $A_d$ (m.) | 59.2 | 134 |
| $S_V$ | - | |
| $S_M$ | 0.00400 | |

Firth River, reach F(WSC)

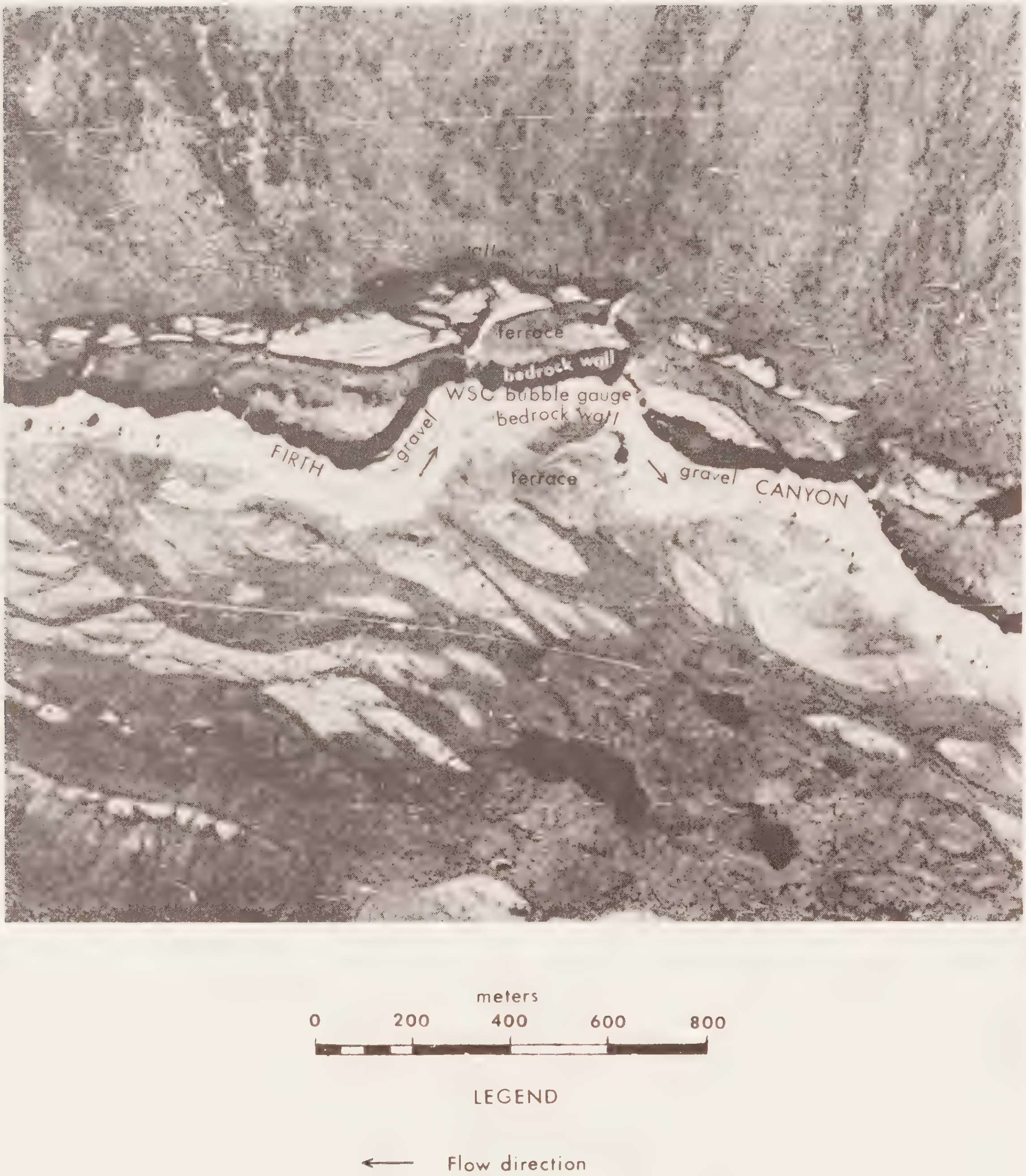



Figure F(WSC):1. Firth River, Water Survey of Canada Gauging Site (Photo A13751-116; 1952).

Figure F(WSC):5 Firth river Canyon, cut in bedrock, at reach F(WSC), showing Water Survey of Canada gauging station; looking downstream. (13 July 1972; GSC 202263-E).

Babbage River, reach B1

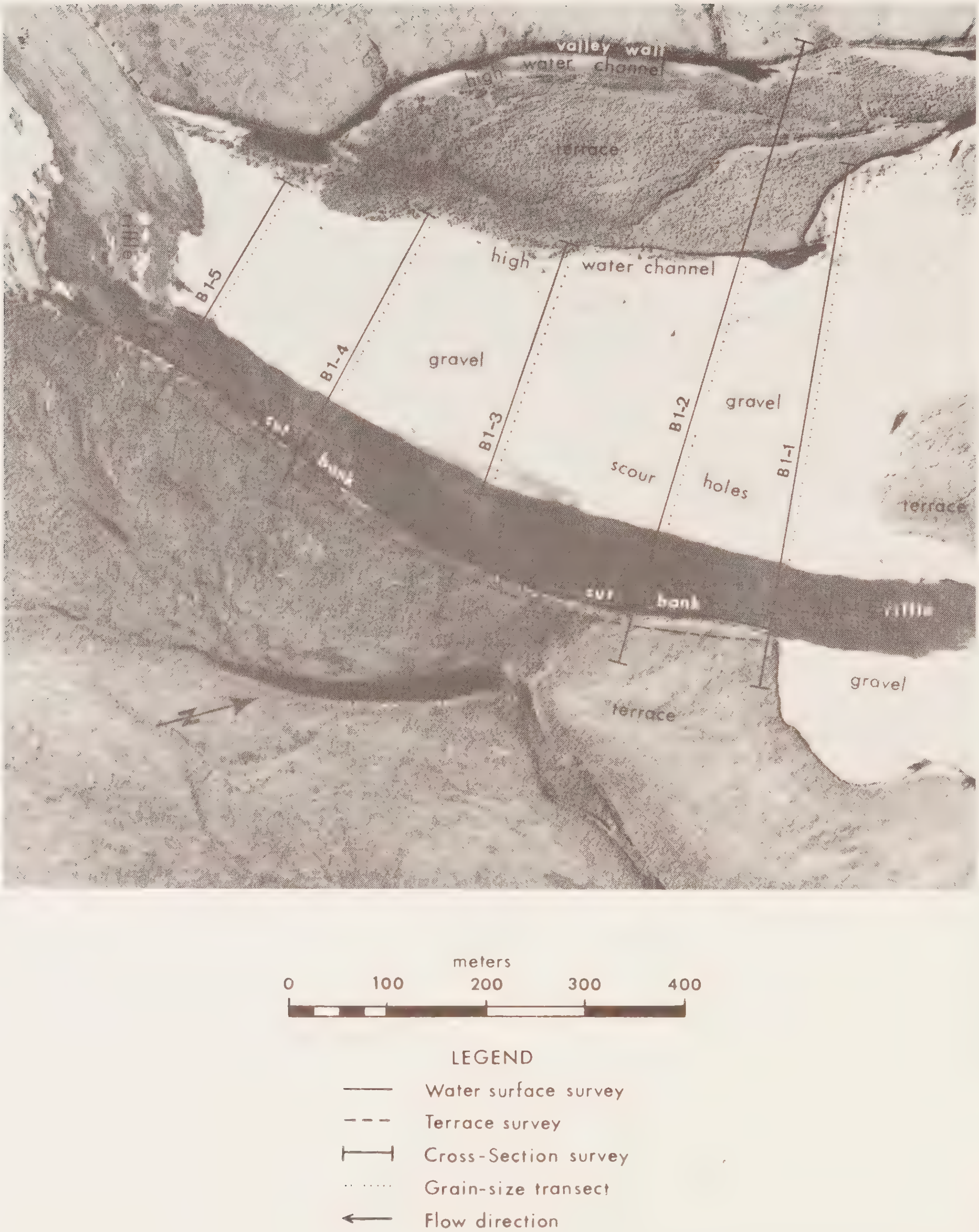



Figure B1:1. Babbage River, Reach B1 (Photo A21826-64; 1970).

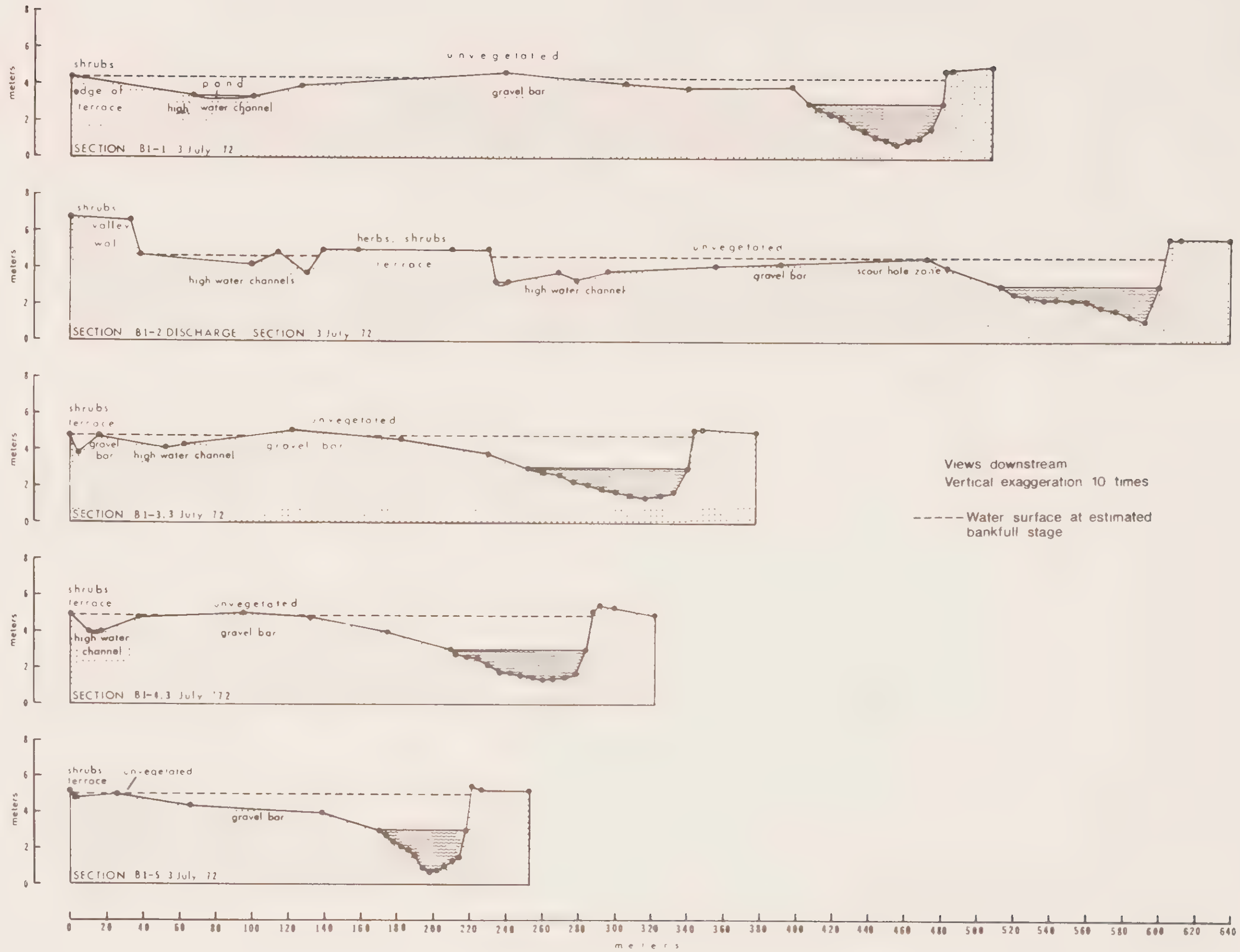



Figure B1:2 Cross-sections, reach B1

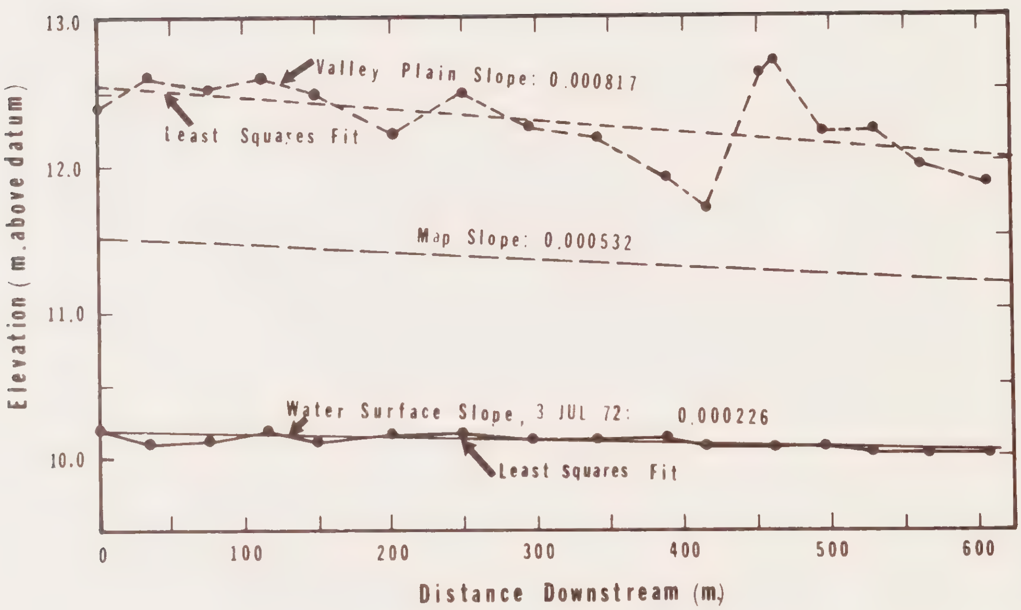



Figure B1:3 Water surface, valley plain and map slopes, reach B1.

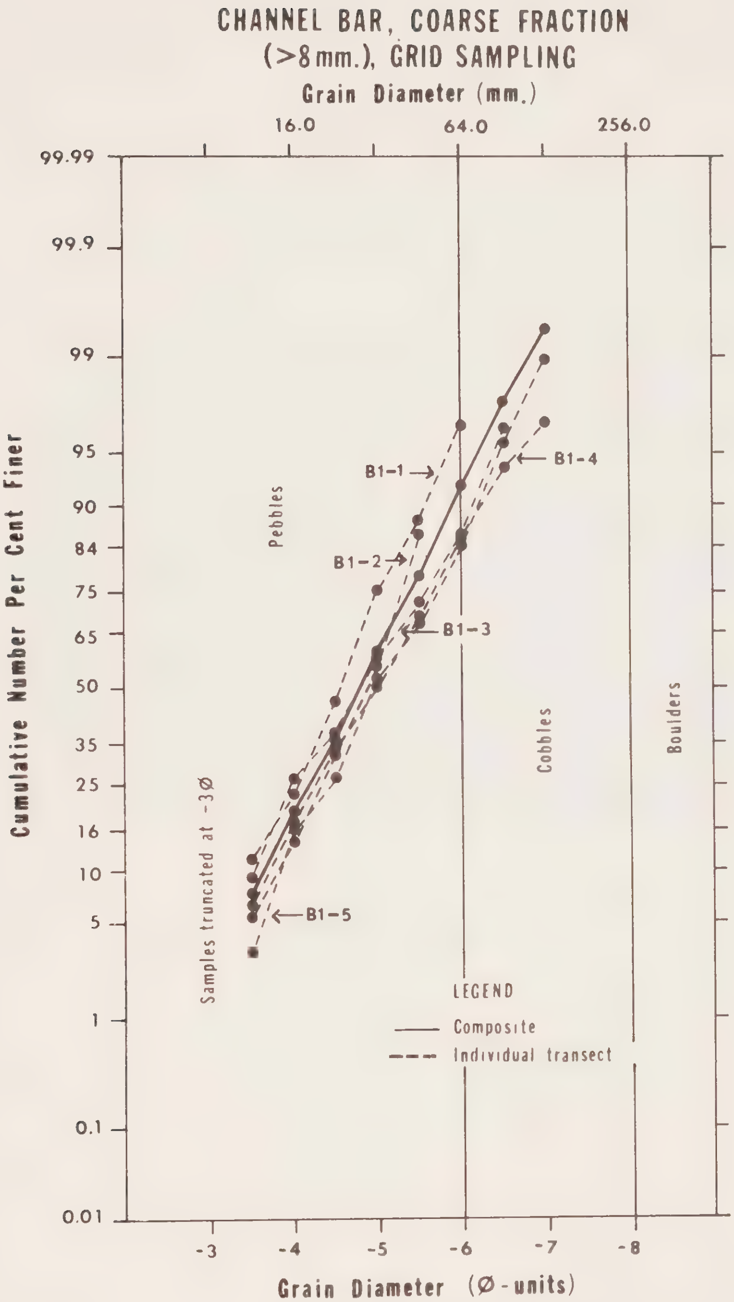



Figure B1:4 Grain-size of surface fluvial sediment, reach B1.

Figure B1:5 Block slumping along right bank, reach B1. (3 July 1972; GSC 202261-I).

(see also Figure 22 in text)

Yukon North Slope Rivers - Hydraulic Data

Reach: Babbage River, B1 Date: 3 Jul 72

a. Grain-size Statistics:

| | mm. | $\phi$ |
|---|---|---|
| $D_m$ | 27.9 | -4.80 |
| $D_{So}$ | | 0.889 (moderate) |
| $D_{Sk}$ | | -0.0172 |
| $D_K$ | | 0.990 |

b. Field Hydraulic Data: mean of 5 cross-sections

| Channel No. | |
|---|---|
| Q ($m.^3$/sec.) | 61.7 |
| $\bar{v}$ (m./sec.) | 0.723 |
| Fr | 0.215 |
| $W_s$ (m.) | 73.9 |
| P (m.) | 76.2 |
| $\bar{d}$ (m.) | 1.16 |
| R (m.) | 1.12 |
| A ($m.^2$) | 85.3 |
| $S_w$ | 0.000226 |
| $c_s$ (mg./l.) | 30 |
| $c_c$ (mg./l.) | 88 |
| T (°C) | 12.8 |

c. Channel Geometry at Estimated Bankfull Stage: mean of 5 cross-sections

| Channel No. | 1 | 2 |
|---|---|---|
| $W_{sd}$ (m.) | 109 | 168 |
| $P_d$ (m.) | 110 | 171 |
| $\bar{d}_d$ (m.) | 0.517 | 1.67 |
| $R_d$ (m.) | 0.512 | 1.63 |
| $A_d$ (m.) | 56.3 | 280 |
| $S_V$ | 0.000817 | |
| $S_M$ | 0.000532 | |

Babbage River, reach B2

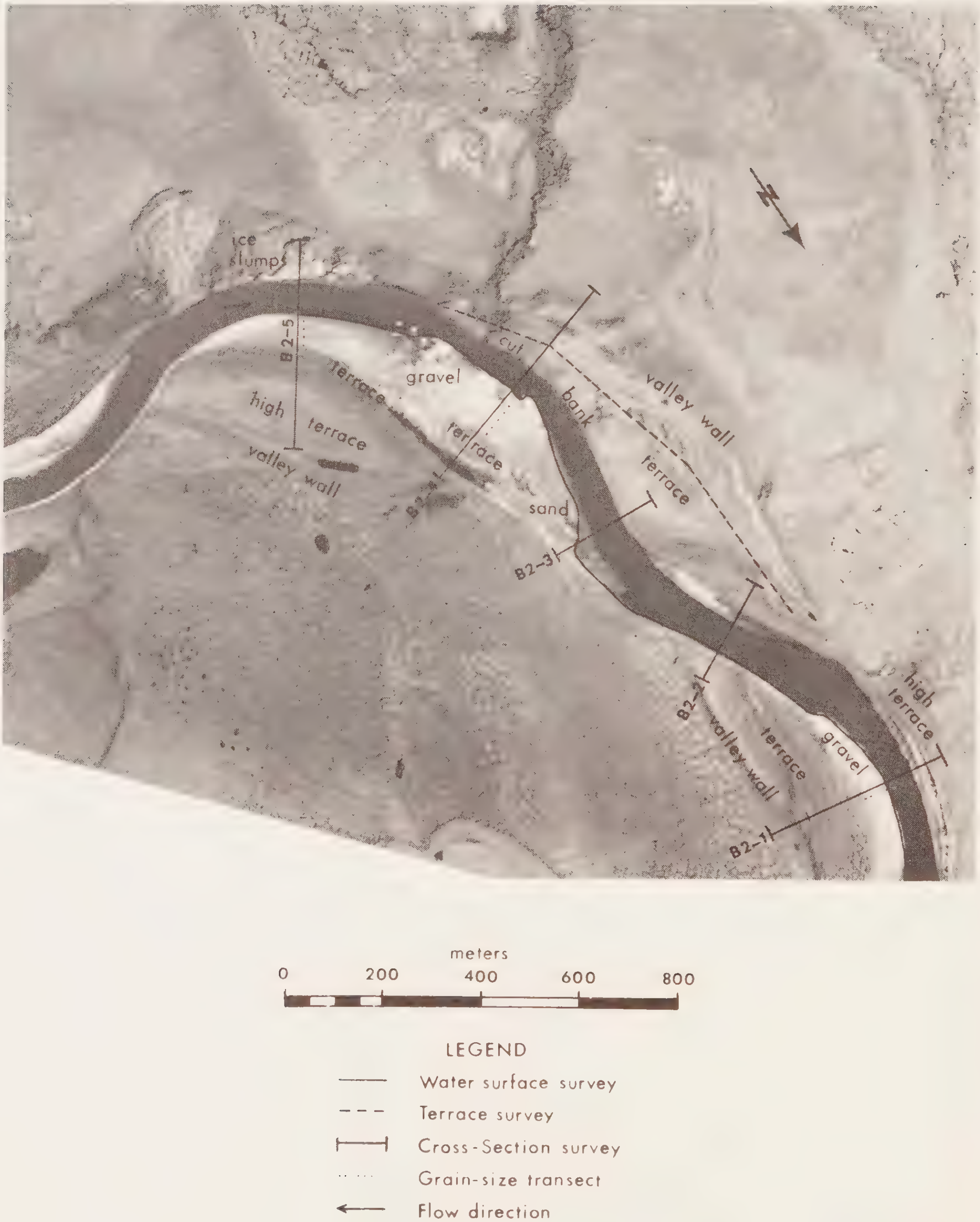



Figure B2:1. Babbage River, Reach B2 (Photo A21825-125; 1970).

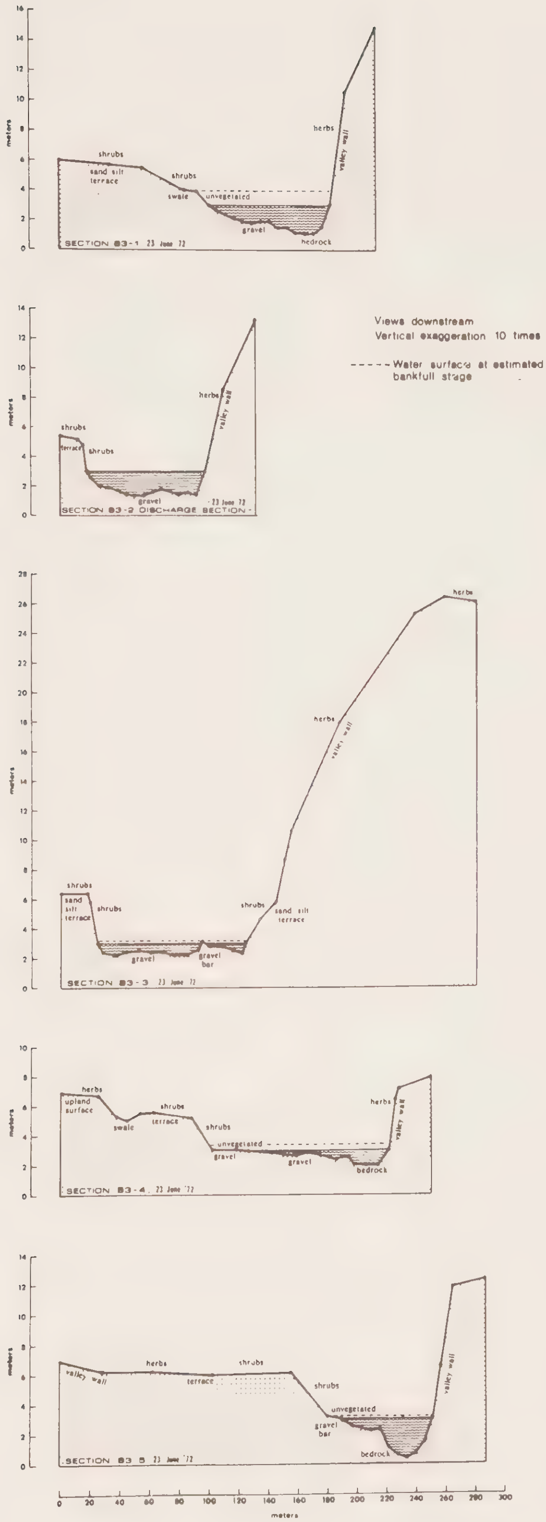



Figure B2:2 Cross-sections, reach B2

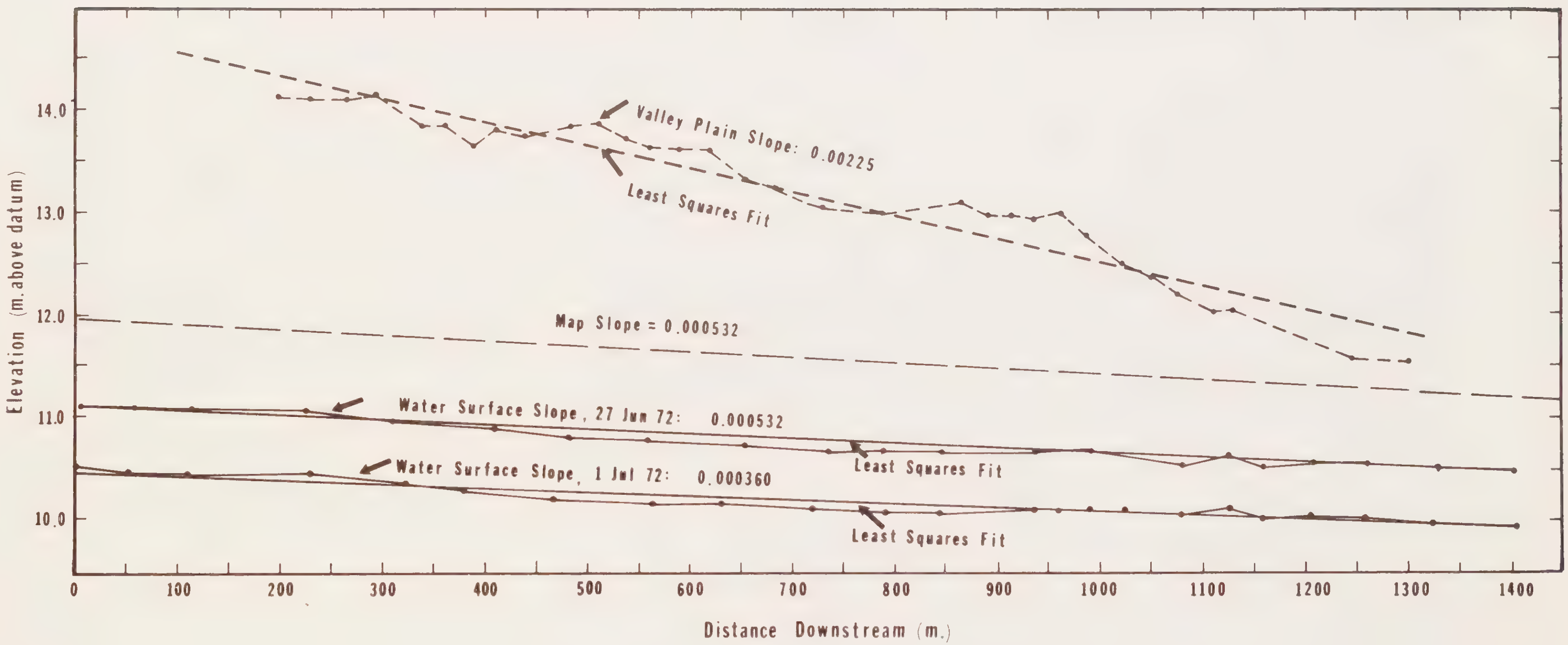



Figure B2:3 Water surface, valley plain and map slopes, reach B2.

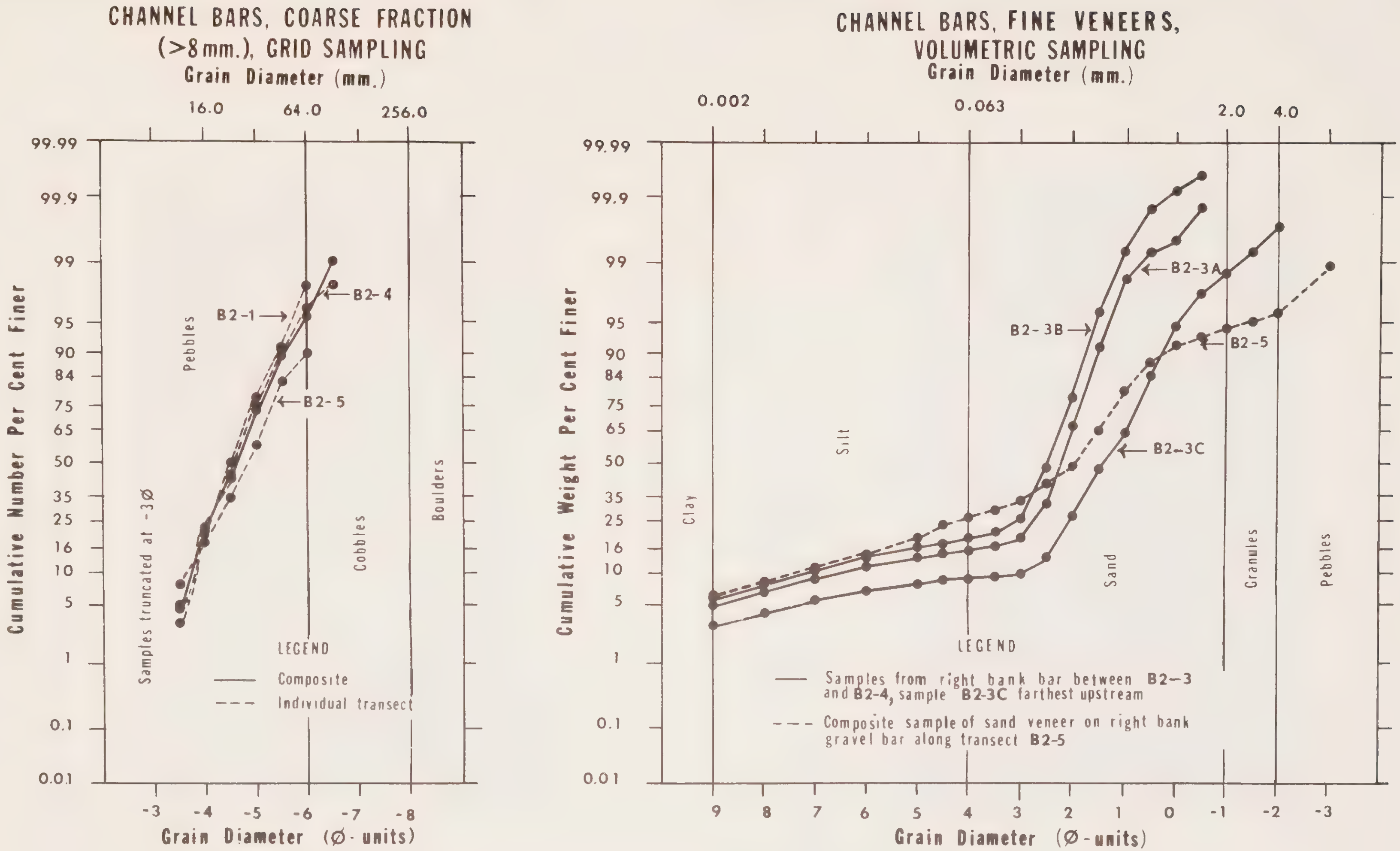



Figure B2:4 Grain-size of surface fluvial sediment, reach B2.

Figure B2:5A Reach B2, looking downstream; tent in right middle distance.
(30 June 1972; GSC 202262-I).

Figure B2:5B Upper limit of ground-ice slump, reach B2.
(30 June 1972; GSC 202261-B).

(see also Figures 9, 10, and 21 in text)

Yukon North Slope Rivers - Hydraulic Data

Reach: Babbage River, B2 Date: see below

a. Grain-size Statistics:

| | mm. | $\phi$ |
|---|---|---|
| $D_m$ | 24.3 | -4.60 |
| $D_{So}$ | | 0.714 (moderate) |
| $D_{Sk}$ | | 0.0625 |
| $D_K$ | | 0.984 |

b(1) Field Hydraulic Data: mean of 5 cross-sections stage = 0.650, 1 July 72

| Channel No. | |
|---|---|
| Q ($m.^3$/sec.) | 73.1 |
| $\bar{v}$ (m./sec.) | 0.589 |
| Fr | 0.159 |
| $W_s$ (m.) | 89.1 |
| P (m.) | 91.9 |
| $\bar{d}$ (m.) | 1.39 |
| R (m.) | 1.35 |
| A ($m.^2$) | 124 |
| $S_w$ | 0.000360 |
| $c_s$ (mg./l.) | 59 |
| $c_c$ (mg./l.) | 44 |
| T (°C) | 10.0 |

Hydraulic Data (cont.) Reach: B2

b(2). Field Hydraulic Data: mean of 5 cross-sections, stage = 1.35 m., 27 J

| Channel No. | |
|---|---|
| Q ($m.^3$/sec.) | 183 |
| $\bar{v}$ (m./sec.) | 1.01 |
| Fr | 0.252 |
| $W_s$ (m.) | 112 |
| P (m.) | 116 |
| $\bar{d}$ (m.) | 1.62 |
| R (m.) | 1.58 |
| A ($m.^2$) | 182 |
| $S_w$ | 0.000430 |
| $c_s$ (mg./l.) | 2225 |
| $c_c$ (mg./l.) | 106 |
| T (°C) | 3.1 |

c. Channel Geometry at Estimated Bankfull Stage: mean of 4 cross-sections

| Channel No. | 1 |
|---|---|
| $W_{sd}$ (m.) | 131 |
| $P_d$ (m.) | 136 |
| $\bar{d}_d$ (m.) | 2.53 |
| $R_d$ (m.) | 2.43 |
| $A_d$ (m.) | 331 |
| $S_V$ | 0.00225 |
| $S_M$ | 0.000532 |

Babbage River, reach B3


Figure B3:1. Babbage River, Reach B3 (Photo A21825-196; 1970).

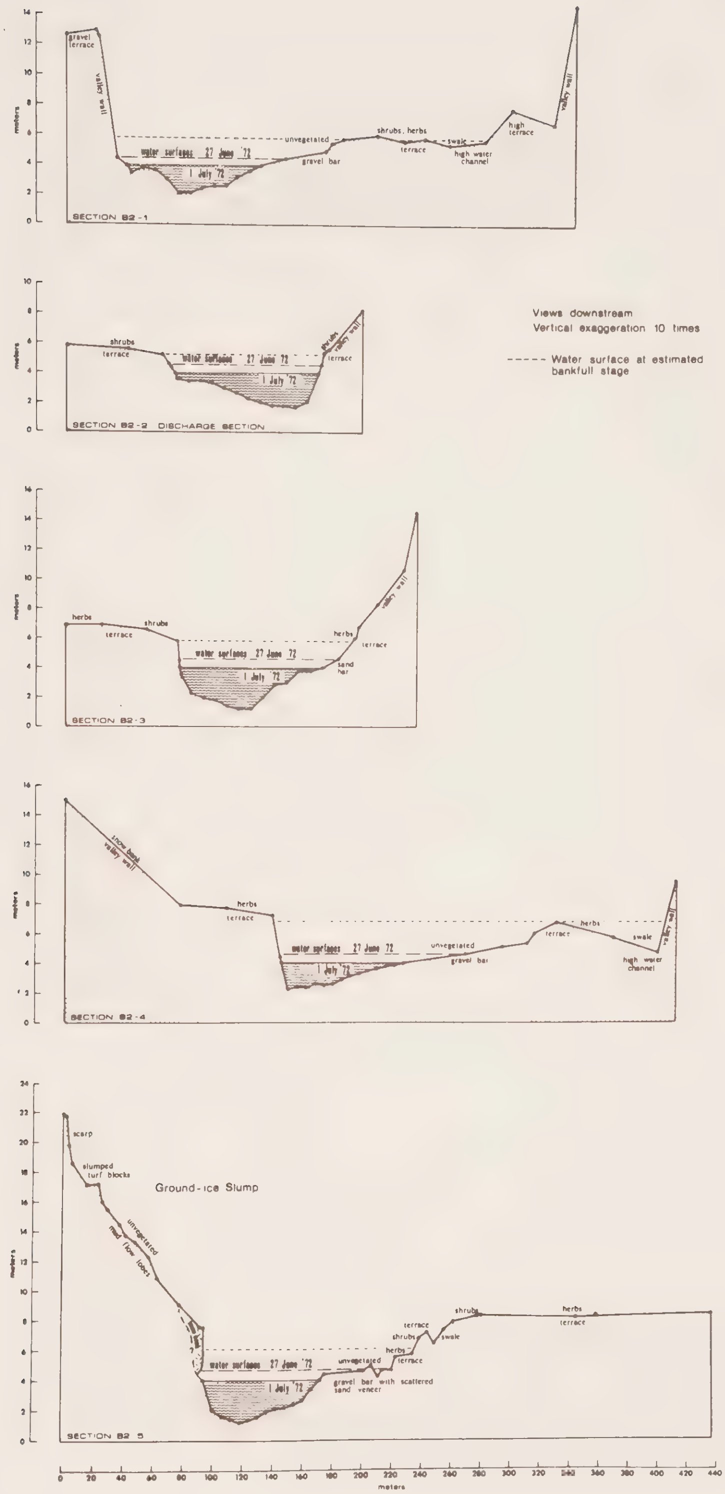



Figure B3:2 Cross-sections, reach B3

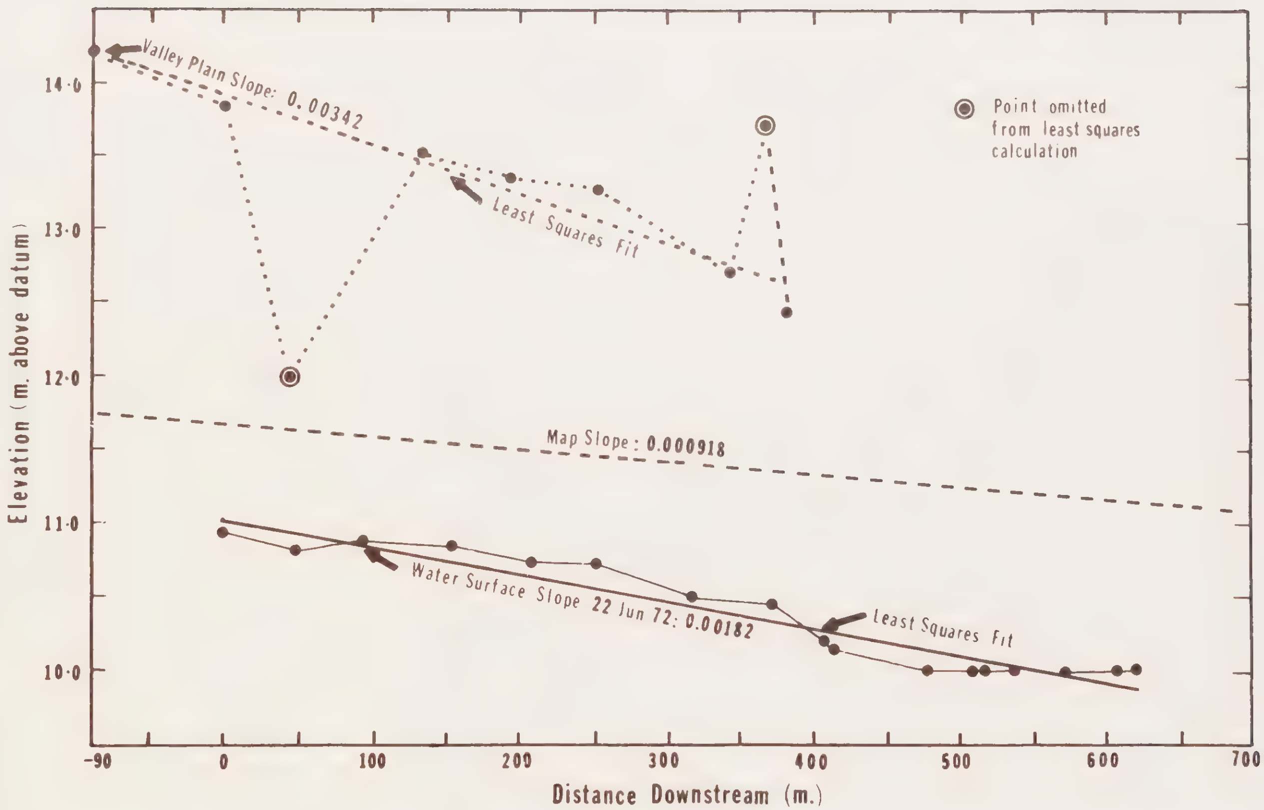



Figure B3:3 Water surface, valley plain and map slopes, reach B3.

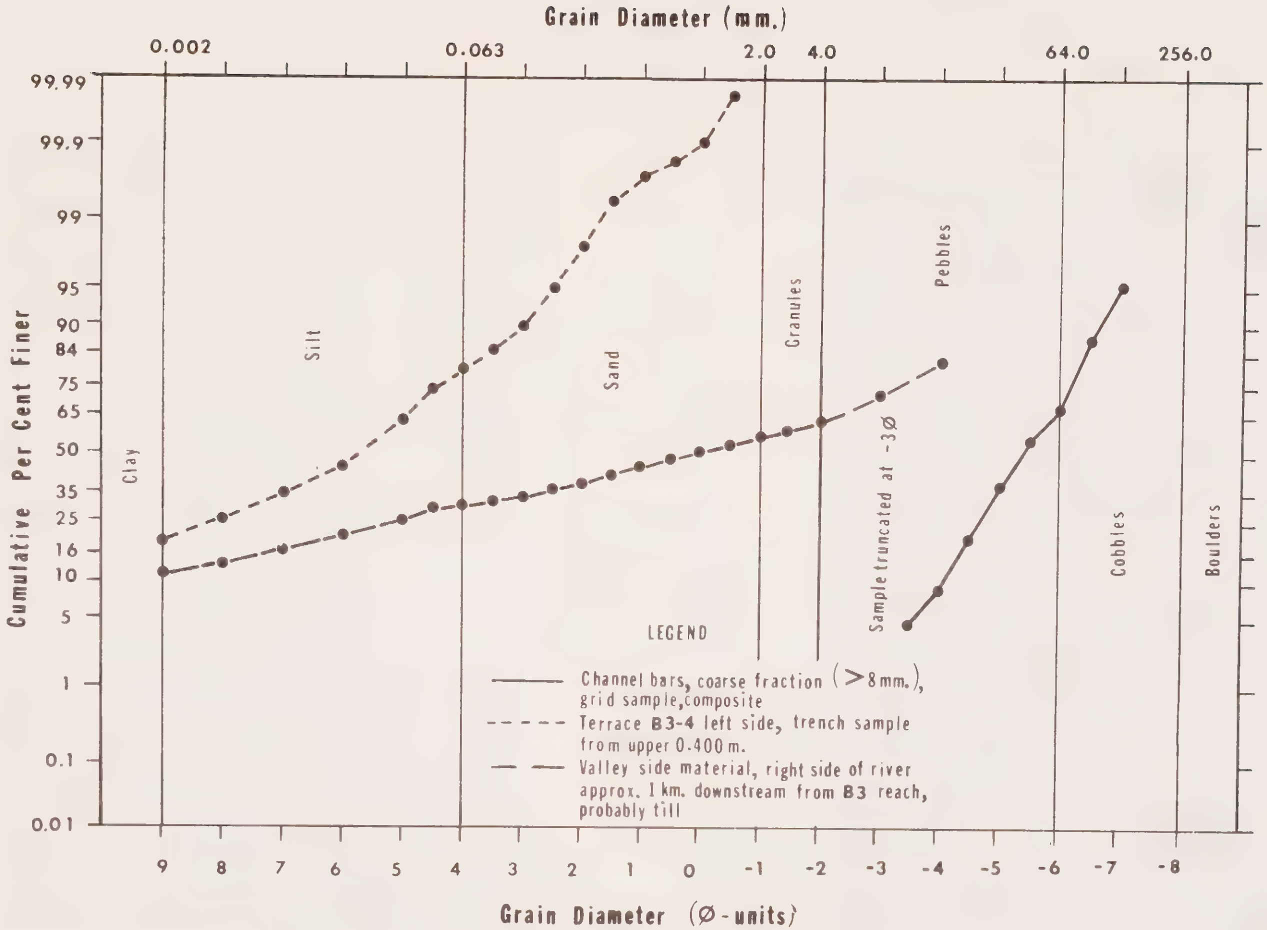



Figure B3:4 Grain-size of bank and surface fluvial sediment, reach B3.

Figure B3:5A Reach B3, looking downstream (25 July 1972; GSC 202262-H).

Figure B3:5B Channel boundary and bed sediment, reach B3; looking downstream. (23 June 1972; GSC 202263-F).

(see also Figure 30 in text)

Yukon North Slope Rivers - Hydraulic Data

Reach: Babbage River, B3

Date: 22 Jun 72

a. Grain-size Statistics:

| | mm. | $\phi$ |
|---|---|---|
| $D_m$ | 41.4 | -5.37 |
| $D_{So}$ | | 0.995 (moderate) |
| $D_{Sk}$ | | 0.0972 |
| $D_K$ | | 0.915 |

b. Field Hydraulic Data: mean of 5 cross-sections

| Channel No. | |
|---|---|
| Q ($m.^3$/sec.) | 39.1 |
| $\bar{v}$ (m./sec.) | 0.505 |
| Fr | 0.168 |
| $W_s$ (m.) | 83.6 |
| P (m.) | 85.5 |
| $\bar{d}$ (m.) | 0.923 |
| R (m.) | 0.903 |
| A ($m.^2$) | 77.2 |
| $S_w$ | 0.00182 |
| $c_s$ (mg./l.) | 17 |
| $c_c$ (mg./l.) | 86 |
| T (°C) | 7.0 |

c. Channel Geometry at Estimated Bankfull Stage: mean of 4 cross-sections

| Channel No. | 1 |
|---|---|
| $W_{sd}$ (m.) | 96.5 |
| $P_d$ (m.) | 98.8 |
| $\bar{d}_d$ (m.) | 1.15 |
| $R_d$ (m.) | 1.12 |
| $A_d$ (m.) | 111 |
| $S_V$ | 0.00342 |
| $S_M$ | 0.000918 |

Babbage River, reach B4

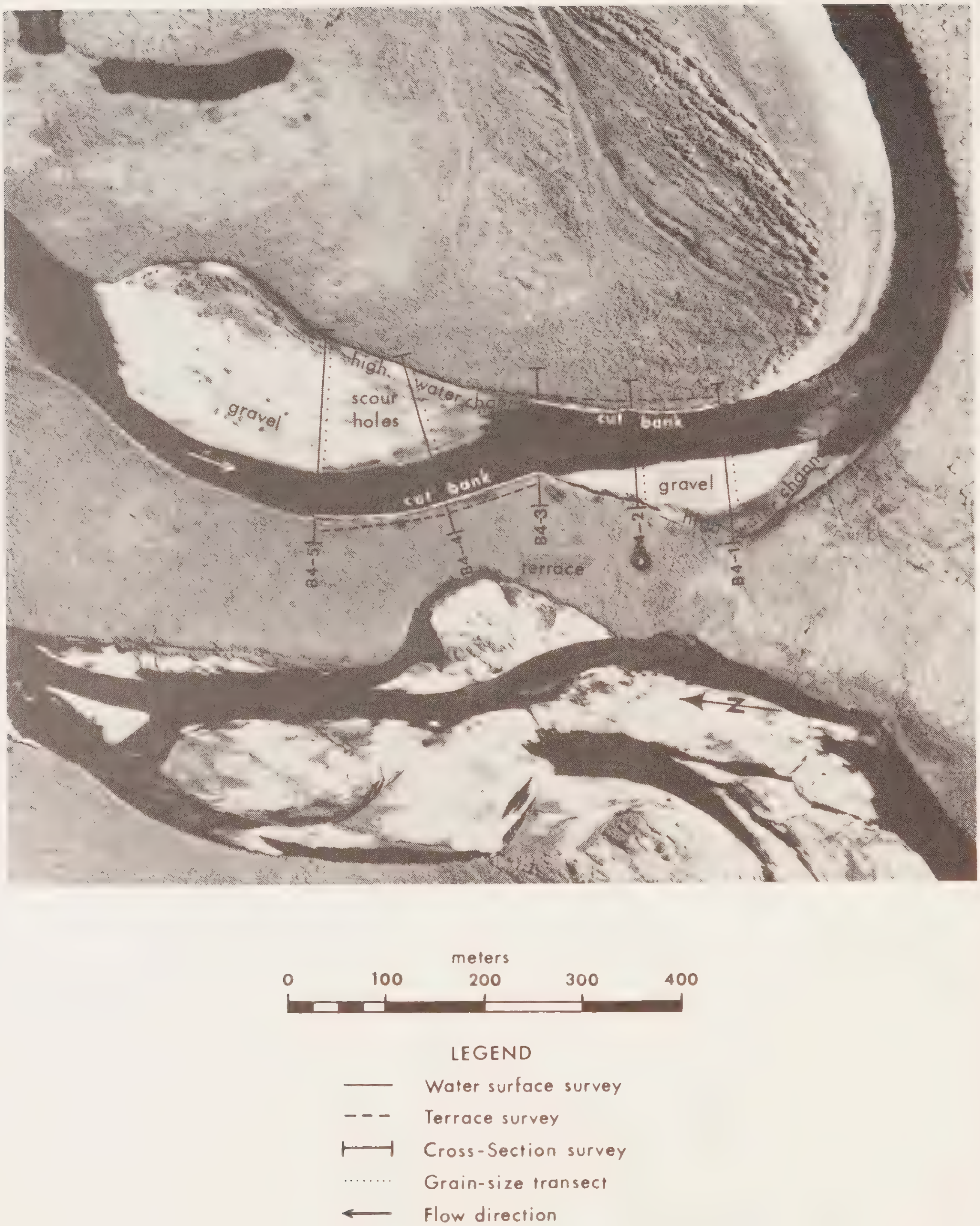



Figure B4:1. Babbage River, Reach B4 (Photo A21824-244; 1970).

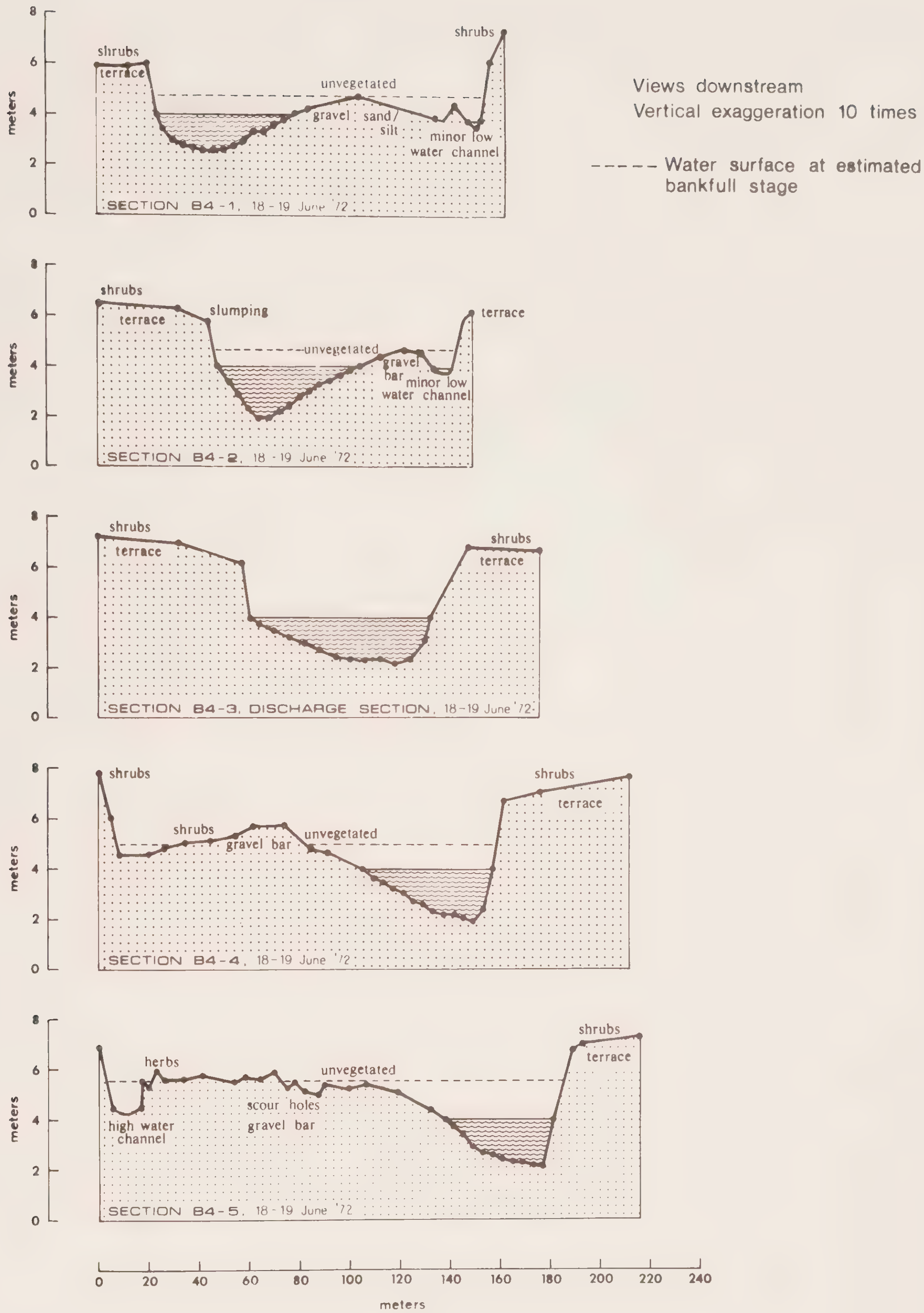



Figure B4:2 Cross-sections, reach B4

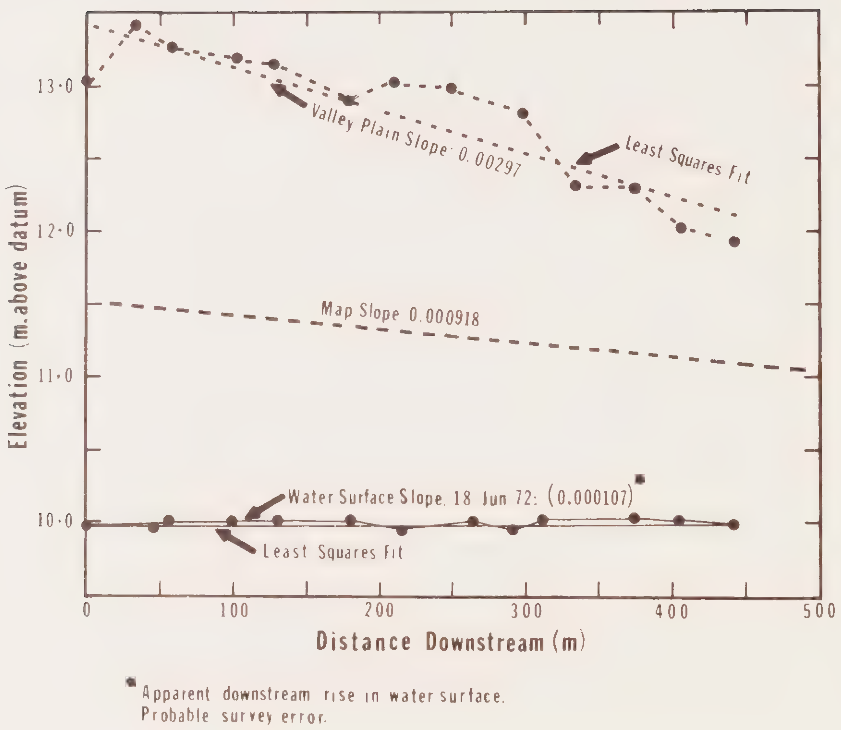



Figure B4:3 Water surface, valley plain and map slopes, reach B4.

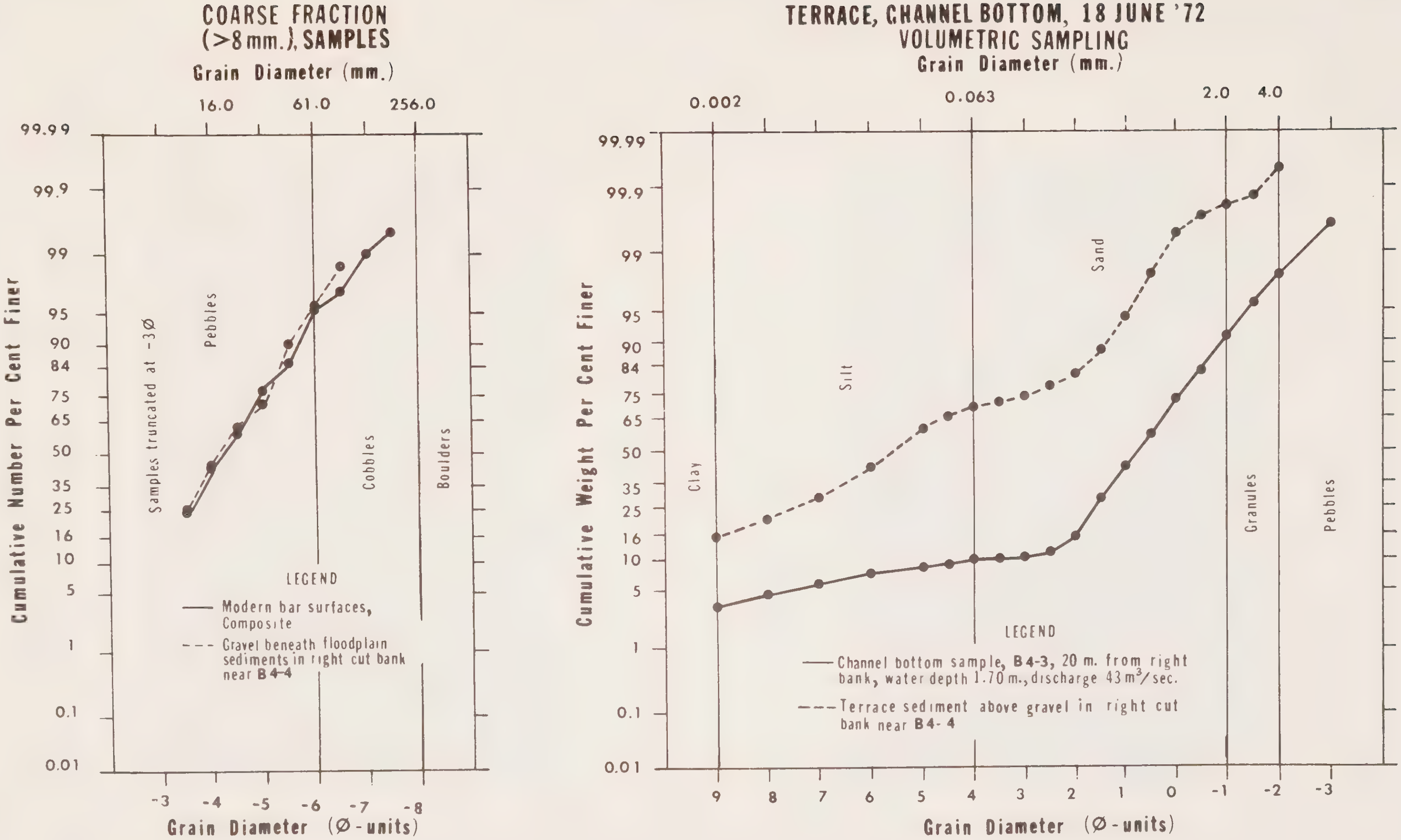



Figure B4:4 Grain-size of bank and surface fluvial sediment, reach B4.

Figure B4:5A    Reach B4, looking upstream.
(25 July 1972; GSC 202261- ).

Figure B4:5B    Scour holes on gravel bar, reach B4; looking downstream.
(20 June 1972; GSC 202262-J).

Yukon North Slope Rivers - Hydraulic Data

Reach: Babbage River, B4 Date: 19 Jun 72

a. Grain-size Statistics:

| | mm. | $\phi$ |
|---|---|---|
| $D_m$ | 20.0 | -4.32 |
| $D_{So}$ | | 1.07 (poor) |
| $D_{Sk}$ | | -0.0445 |
| $D_K$ | | 1.01 |

b. Field Hydraulic Data: mean of 5 cross-sections

| Channel No. | |
|---|---|
| Q (m.$^3$/sec.) | 41.8 |
| $\bar{v}$ (m./sec.) | 0.641 |
| Fr | 0.188 |
| $W_s$ (m.) | 55.3 |
| P (m.) | 57.7 |
| $\bar{d}$ (m.) | 1.18 |
| R (m.) | 1.13 |
| A (m.$^2$) | 65.3 |
| $S_W$ | - |
| $c_s$ (mg./l.) | 55 |
| $c_c$ (mg./l.) | 116 |
| T (°C) | 8.6 |

c. Channel Geometry at Estimated Bankfull Stage: mean of 4 cross-sections

| Channel No. | 1 |
|---|---|
| $W_{sd}$ (m.) | 86.5 |
| $P_d$ (m.) | 89.3 |
| $\bar{d}_d$ (m.) | 1.42 |
| $R_d$ (m.) | 1.38 |
| $A_d$ (m.) | 123 |
| $S_V$ | 0.00297 |
| $S_M$ | 0.000918 |

Babbage River, reach B5


Figure B5:1. Babbage River, Reach B5 (Photo A21924-199; 1970).

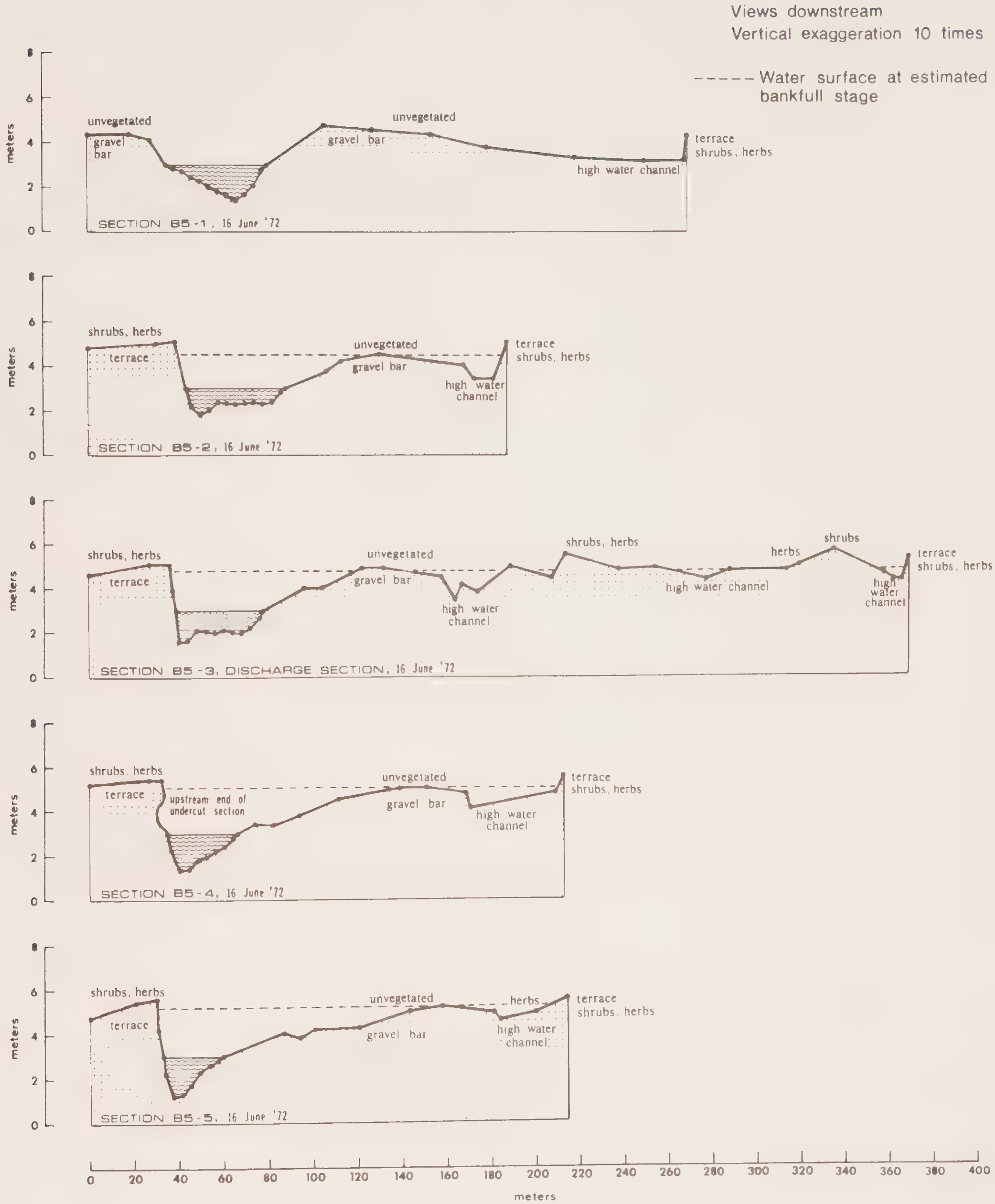



Figure B5:2 Cross-sections, reach B5

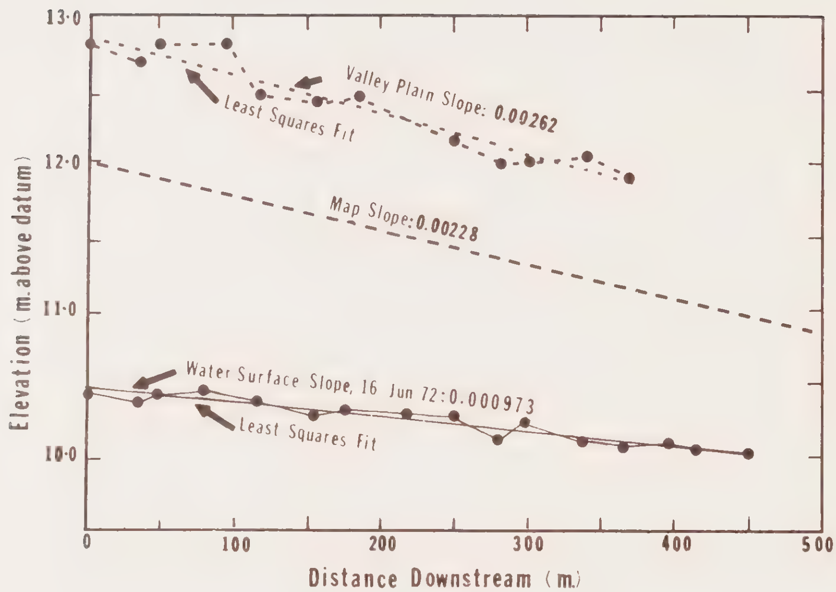



Figure B5:3 Water surface, valley plain and map slopes, reach B5.

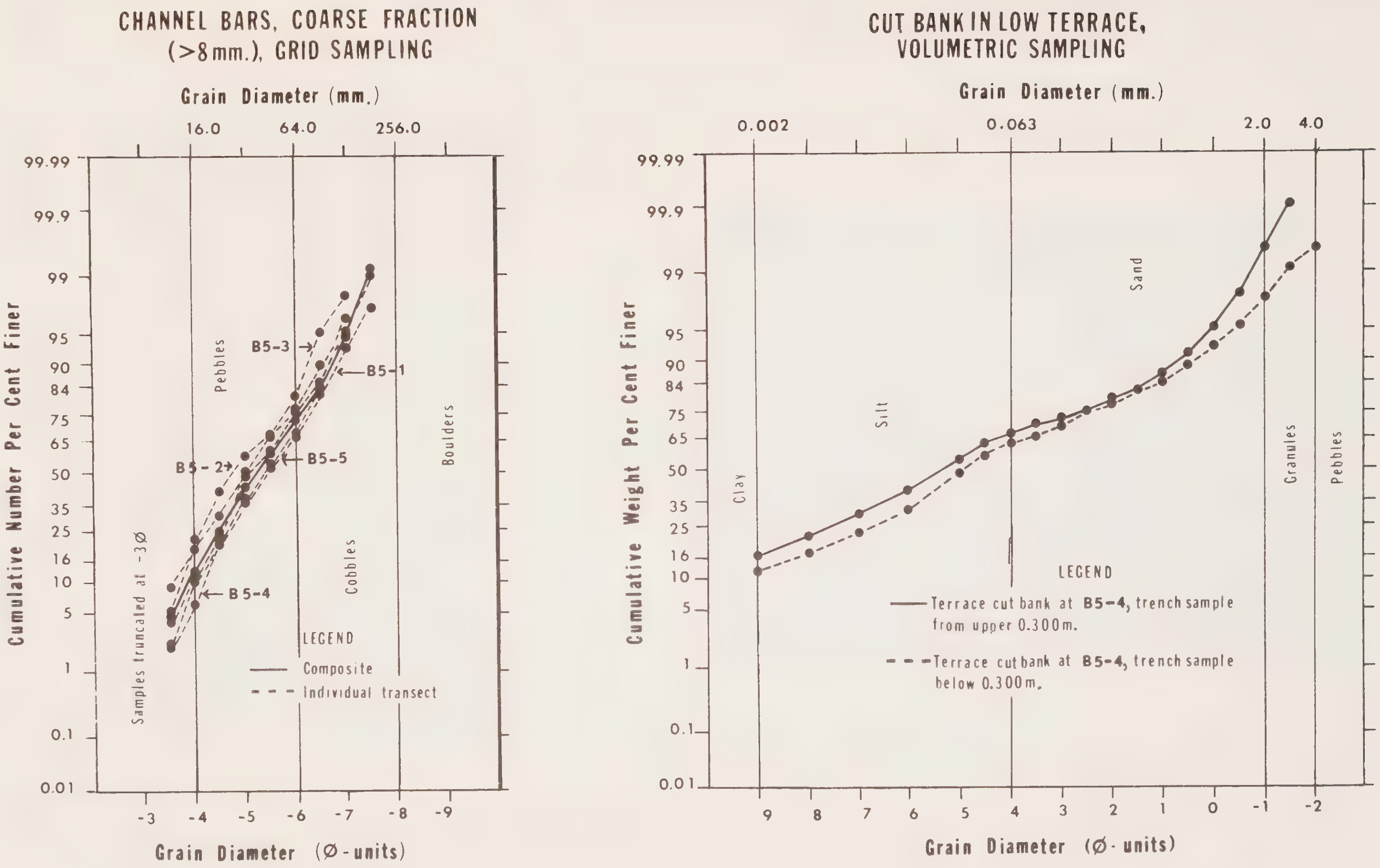



Figure B5:4 Grain-size of bank and surface fluvial sediment, reach B5.

Figure B5:5A Reach B5, looking upstream; block slumping visible where flow impinges on vegetated, finer-grained bank. (25 July 1972; GSC 202263-C).

Figure B5:5B Block slumping and collapse of undercut bank, reach B5. (17 June 1972; GSC 202261-A).

(see also Figures 23,24 and 28 in text)

Yukon North Slope Rivers - Hydraulic Data

Reach: Babbage River, B5 — Date: 15 Jun 72

a. Grain-size Statistics:

| | mm. | $\phi$ |
|---|---|---|
| $D_m$ | 39.9 | -5.32 |
| $D_{So}$ | | 1.09 (poor) |
| $D_{Sk}$ | | -0.0773 |
| $D_K$ | | 0.883 |

b. Field Hydraulic Data: mean of 5 cross-sections

| Channel No. | |
|---|---|
| Q ($m.^3$/sec.) | 38.4 |
| $\bar{v}$ (m./sec.) | 1.16 |
| Fr | 0.389 |
| $W_s$ (m.) | 37.1 |
| P (m.) | 38.9 |
| $\bar{d}$ (m.) | 0.897 |
| R (m.) | 0.856 |
| A ($m.^2$) | 33.3 |
| $S_w$ | 0.000973 |
| $c_s$ (mg./l.) | 65 |
| $c_c$ (mg./l.) | 98 |
| T (°C) | 7.1 |

c. Channel Geometry at Estimated Bankfull Stage: mean of 4 cross-sections

| Channel No. | 1 | 2 |
|---|---|---|
| $W_{sd}$ (m.) | 98.5 | 41.0 |
| $P_d$ (m.) | 102 | 42.0 |
| $\bar{d}_d$ (m.) | 1.56 | 0.510 |
| $R_d$ (m.) | 1.52 | 0.497 |
| $A_d$ (m.) | 154 | 20.9 |
| $S_V$ | 0.00262 | |
| $S_M$ | 0.00228 | |

Running River, reach RU1

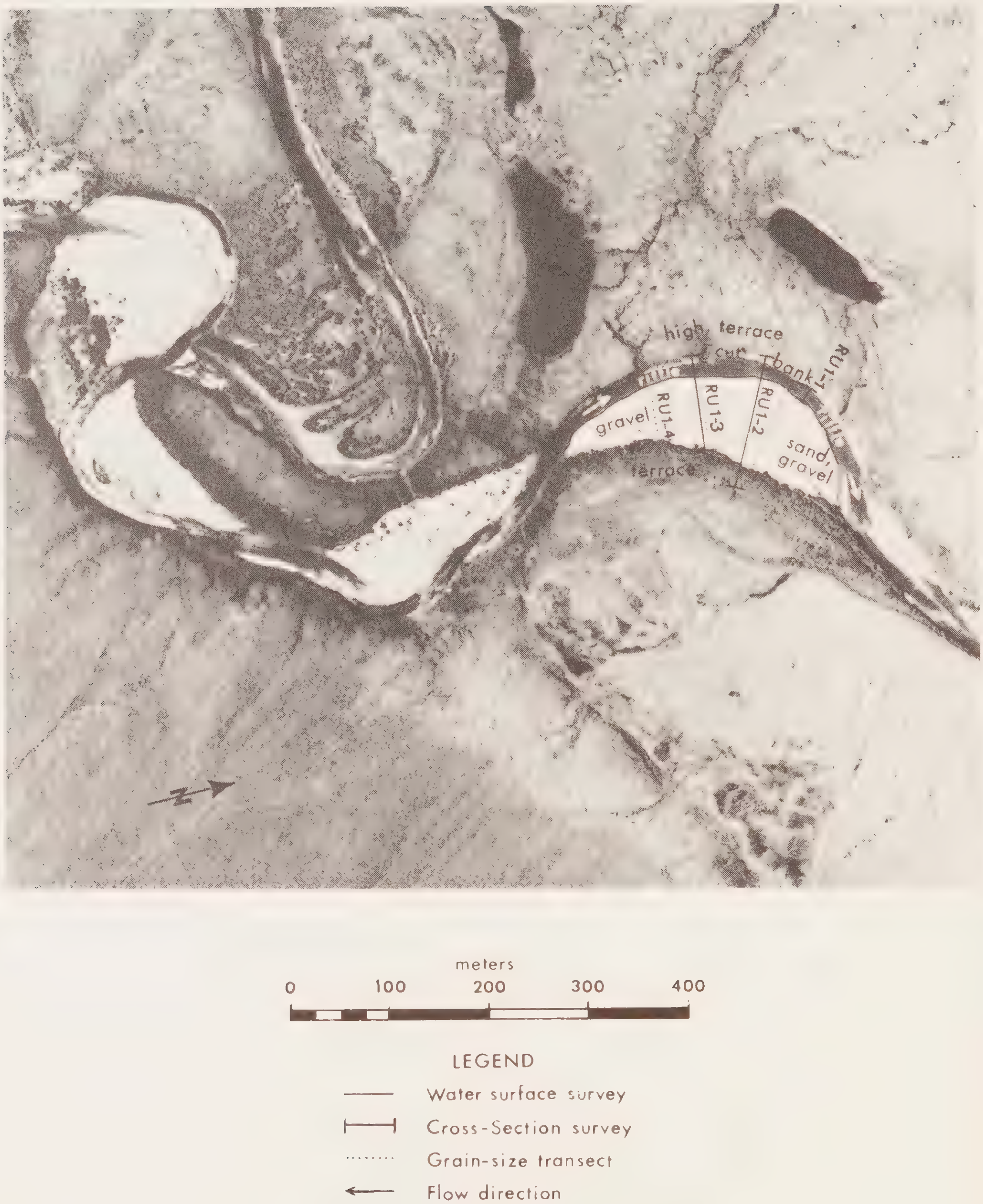



Figure RU1:1. Running River, Reach RU1 (Photo A21831-74; 1970).

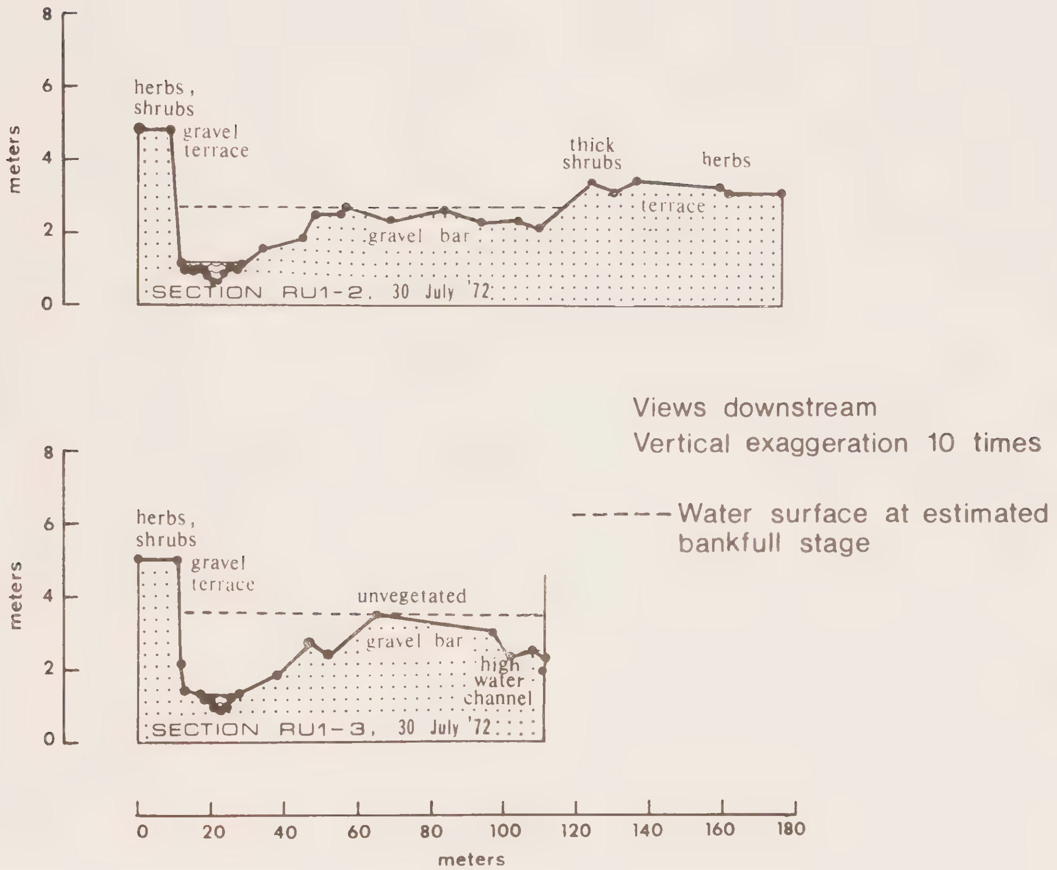



Figure RU1:2 Cross-sections, reach RU1

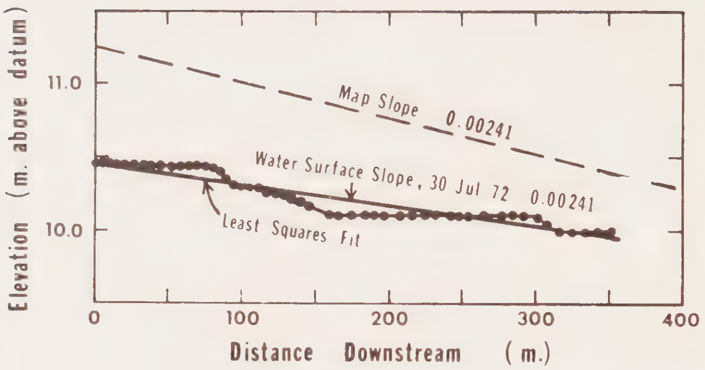



Figure RU1:3 Water surface and map slopes, reach RU1.

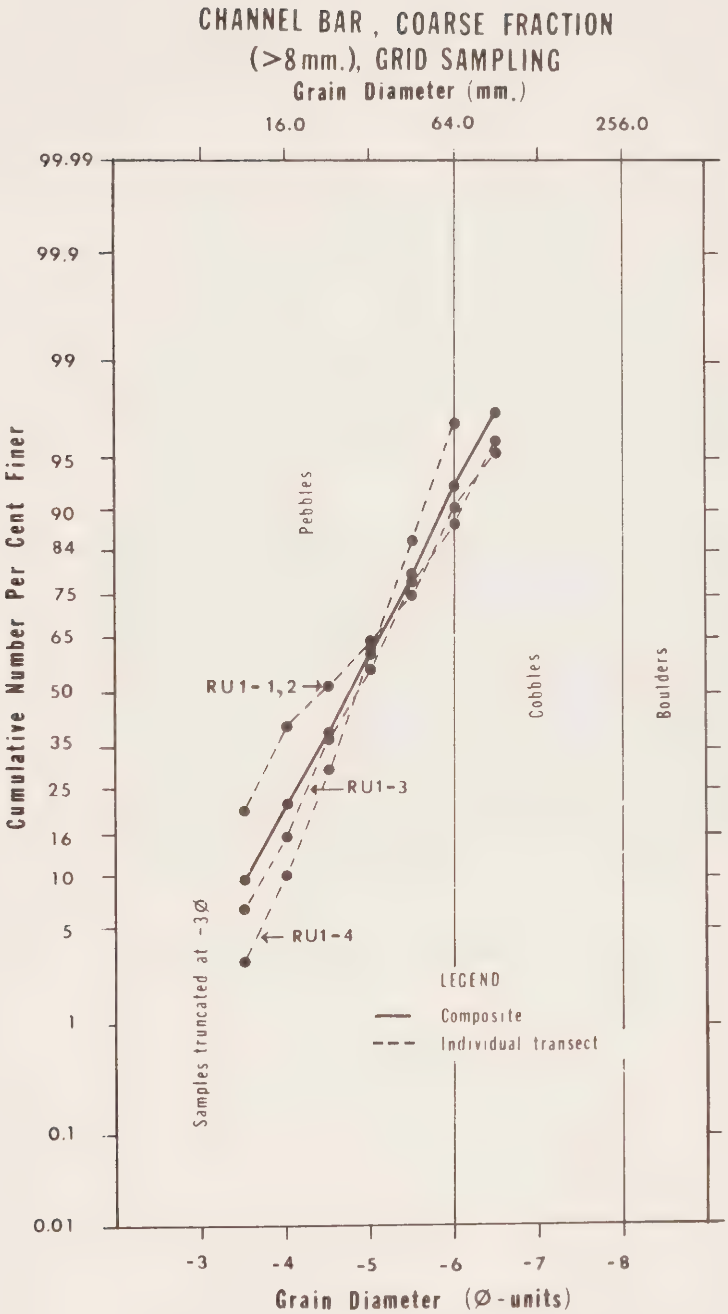



Figure RU1:4 Grain-size of surface fluvial sediment, reach RU1.

Figure RU1:5 Gravel on point bar, reach RU1. (30 July 1972; GSC 202263-I).

(see also Figure 17 in text)

Yukon North Slope Rivers - Hydraulic Data

Reach: Running River, Ru1 Date: 30 Jul 72

a. Grain-size Statistics:

| | mm. | $\phi$ |
|---|---|---|
| $D_m$ | 26.5 | -4.73 |
| $D_{So}$ | | 0.917 (moderate) |
| $D_{Sk}$ | | -0.0302 |
| $D_K$ | | 0.984 |

b. Field Hydraulic Data: mean of 3 cross-sections

| Channel No. | |
|---|---|
| Q ($m.^3$/sec.) | 0.382[1] |
| $\bar{v}$ (m./sec.) | 0.103 |
| Fr | 0.0651 |
| $W_s$ (m.) | 14.4 |
| P (m.) | 14.9 |
| $\bar{d}$ (m.) | 0.257 |
| R (m.) | 0.248 |
| A ($m.^2$) | 3.69 |
| $S_w$ | 0.00144 |
| $c_s$ (mg./l.) | - |
| $c_c$ (mg./l.) | - |
| T (°C) | - |

c. Channel Geometry at Estimated Bankfull Stage: mean of 2 cross-sections

| Channel No. | 1 | 2 |
|---|---|---|
| $W_{sd}$ (m.) | 50.0 | 35.0 |
| $P_d$ (m.) | 52.7 | 35.7 |
| $\bar{d}_d$ (m.) | 1.35 | 0.354 |
| $R_d$ (m.) | 1.28 | 0.347 |
| $A_d$ (m.) | 67.3 | 12.4 |
| $S_V$ | - | |
| $S_M$ | 0.00241 | |

[1] Based on float velocity data

Blow River, reach BL1


Figure BL1:1. Blow River, Reach BL1 (Photo A21919-4; 1970).

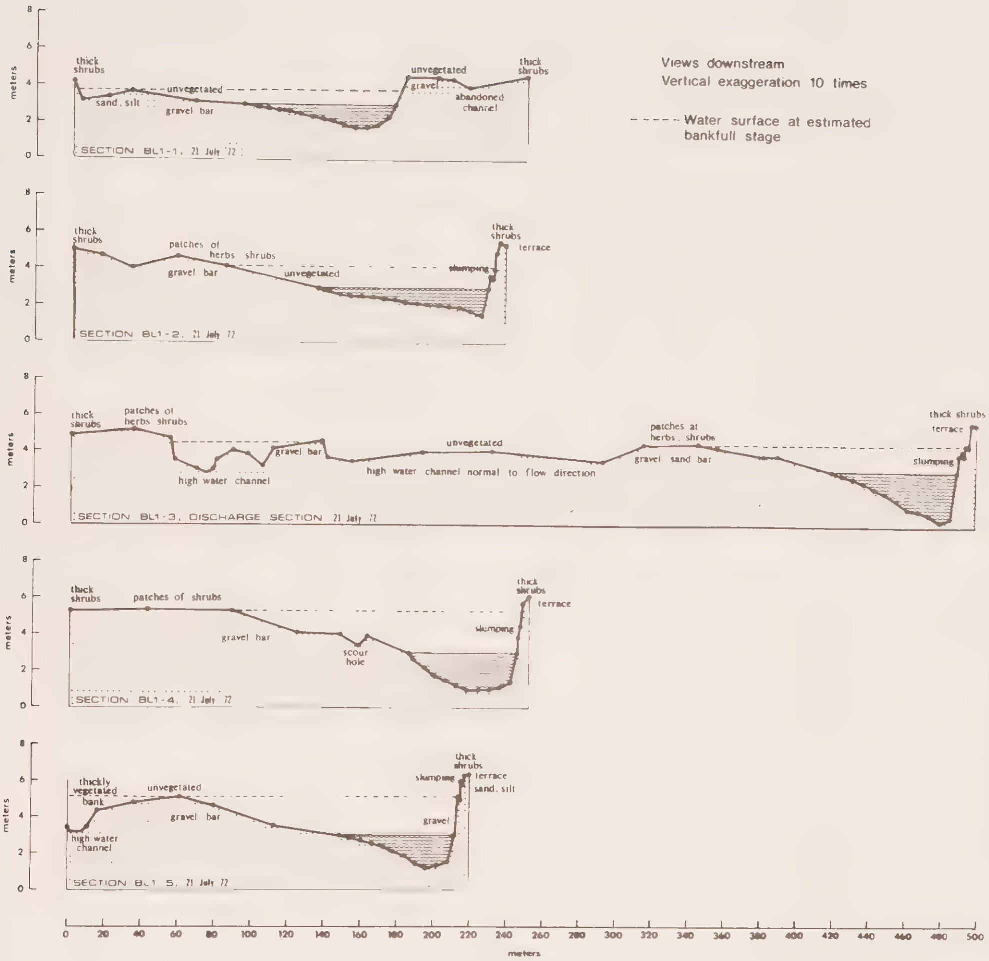



Figure BL1:2 Cross-sections, reach BL1

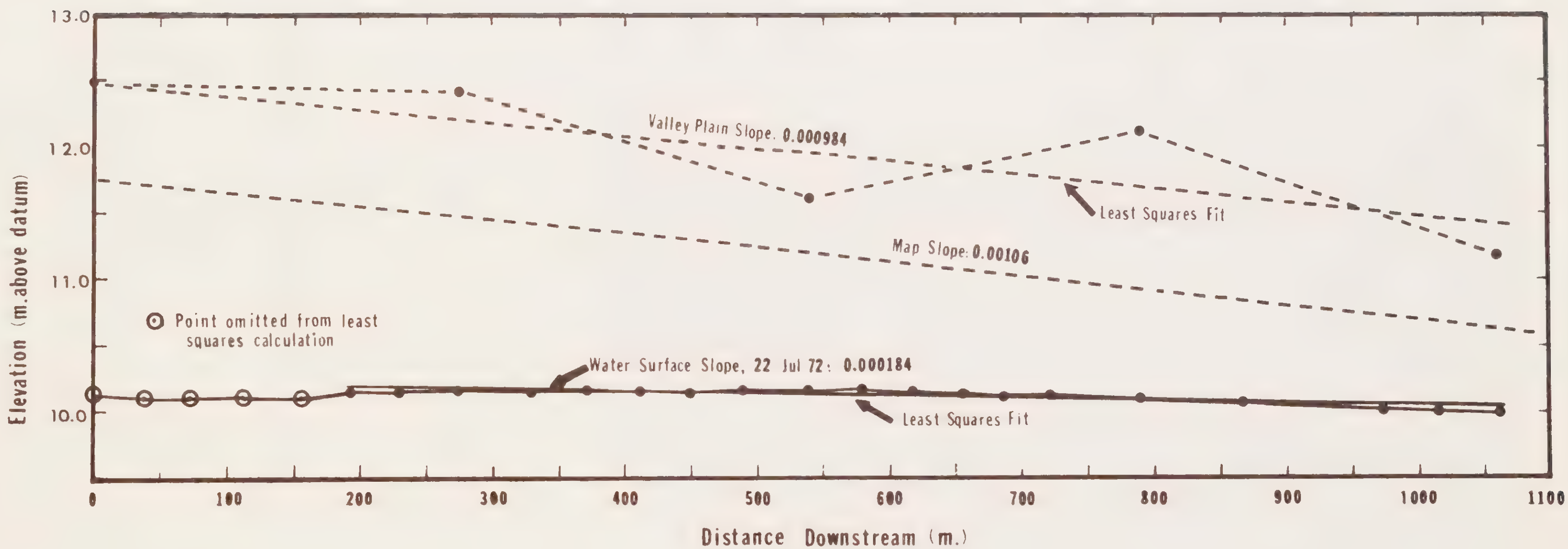



Figure BL1:3 Water surface, valley plain and map slopes, reach BL1.

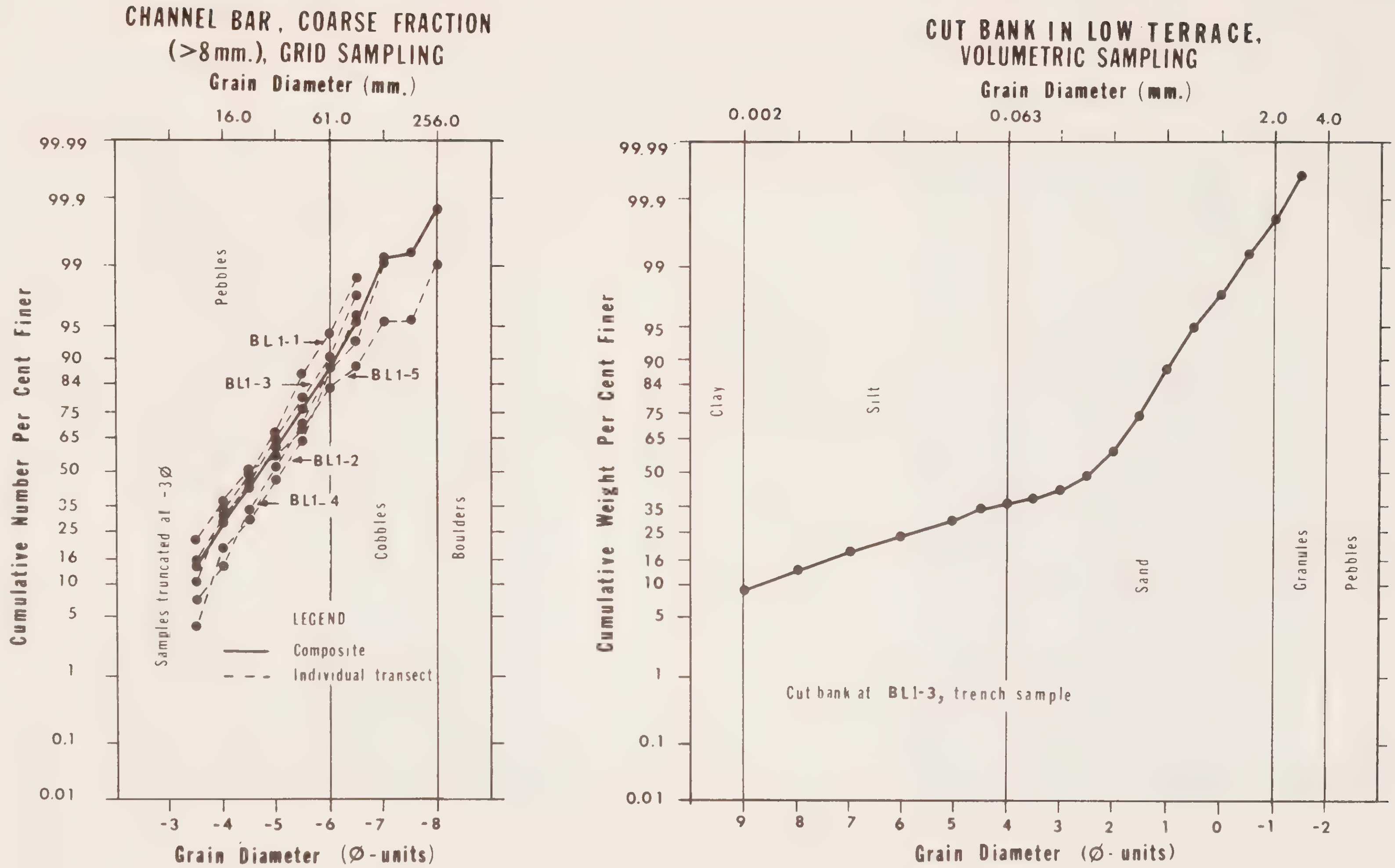



Figure BL1:4 Grain-size of bank and surface fluvial sediment, reach BL1.

Figure BL1:5A Bar sediment along west high-water channel, reach BL1; man as scale. (28 July 1972; GSC 202263-J).

Figure BL1:5B Thickly vegetated bank near BL1-4, reach BL1, looking upstream. (23 July 1972; GSC 202262-Z).

Yukon North Slope Rivers - Hydraulic Data

Reach: Blow River, BL1 — Date: 22 Jul 72

a. Grain-size Statistics:

| | mm. | $\phi$ |
|---|---|---|
| $D_m$ | 26.0 | -4.70 |
| $D_{So}$ | | 1.08 (poor) |
| $D_{Sk}$ | | 0.0143 |
| $D_K$ | | 0.897 |

b. Field Hydraulic Data: mean of 5 cross-sections

| Channel No. | |
|---|---|
| Q ($m.^3$/sec.) | 33.0 |
| $\bar{v}$ (m./sec.) | 0.441 |
| Fr | 0.140 |
| $W_s$ (m.) | 74.3 |
| P (m.) | 76.3 |
| $\bar{d}$ (m.) | 1.01 |
| R (m.) | 0.982 |
| A ($m.^2$) | 74.9 |
| $S_w$ | 0.000184 |
| $c_s$ (mg./l.) | 2 |
| $c_c$ (mg./l.) | 152 |
| T (°C) | 12.1 |

c. Channel Geometry at Estimated Bankfull Stage: mean of 5 cross-sections

| Channel No. | 1 | 2 |
|---|---|---|
| $W_{sd}$ (m.) | 60.0 | 147 |
| $P_d$ (m.) | 61.5 | 150 |
| $\bar{d}_d$ (m.) | 0.750 | 1.67 |
| $R_d$ (m.) | 0.732 | 1.63 |
| $A_d$ (m.) | 45.0 | 245 |
| $S_V$ | - | |
| $S_M$ | 0.00106 | |

Blow River, reach BL2

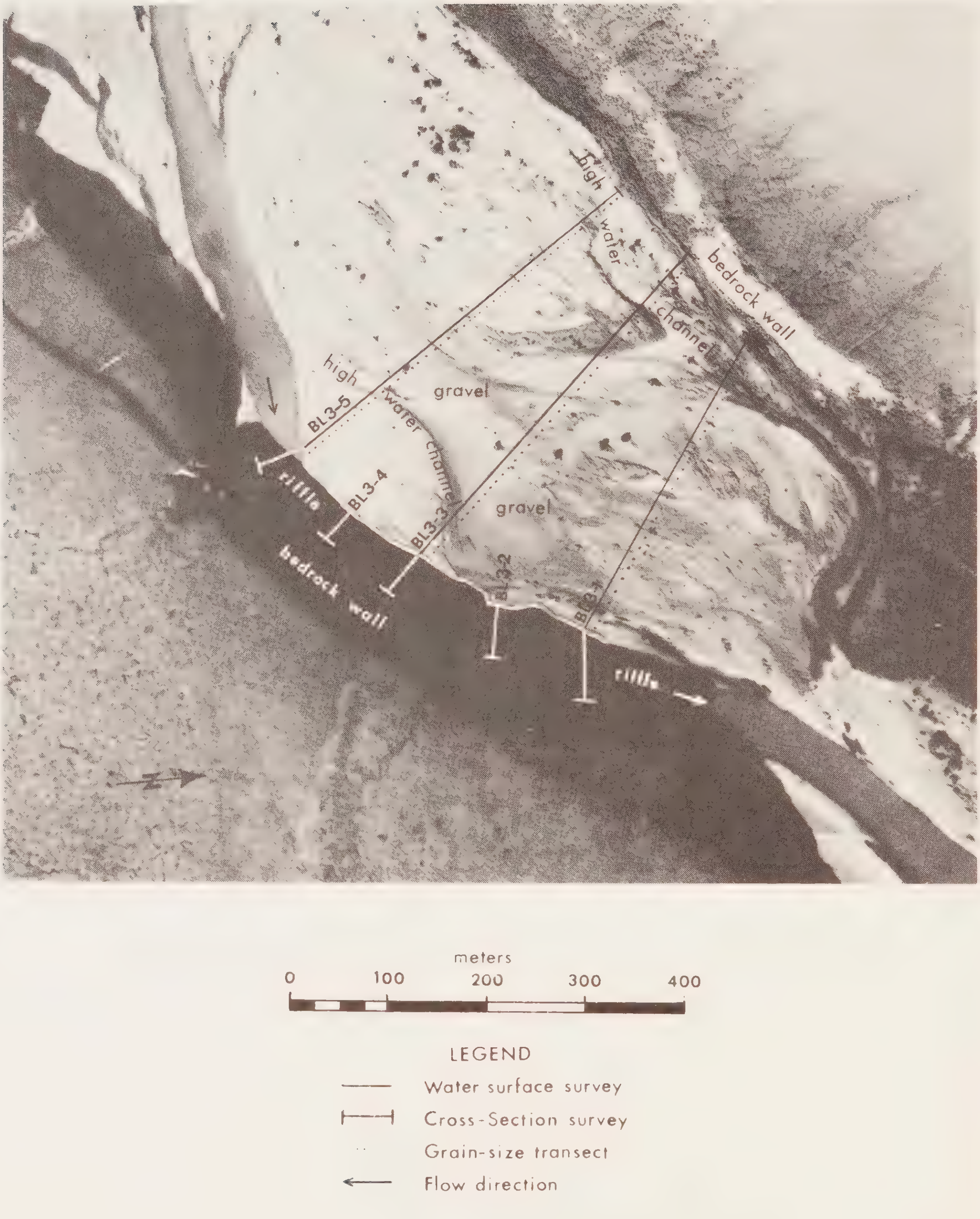



Figure BL2:1. Blow River, Reach BL2 (Photo A21922-91; 1970).

NOTE: "BL3" on photograph should read "BL2"


Figure BL2:2 Cross-sections, reach BL2

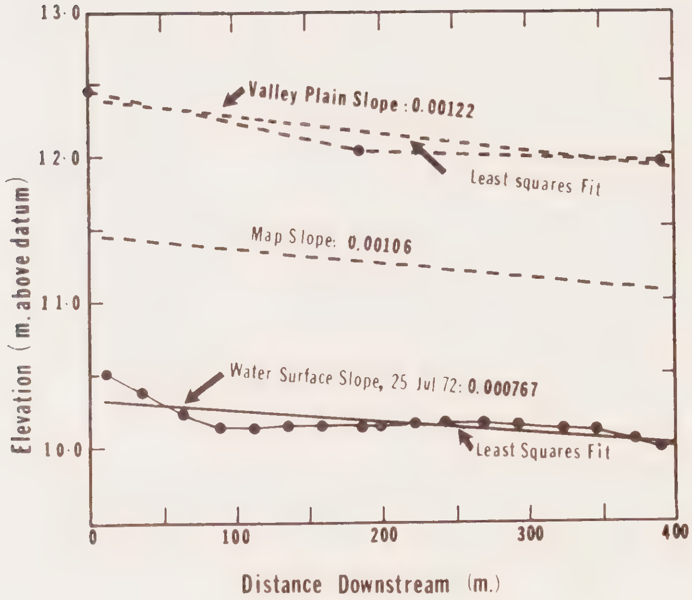



Figure BL2:3 Water surface, valley plain and map slopes, reach BL2.

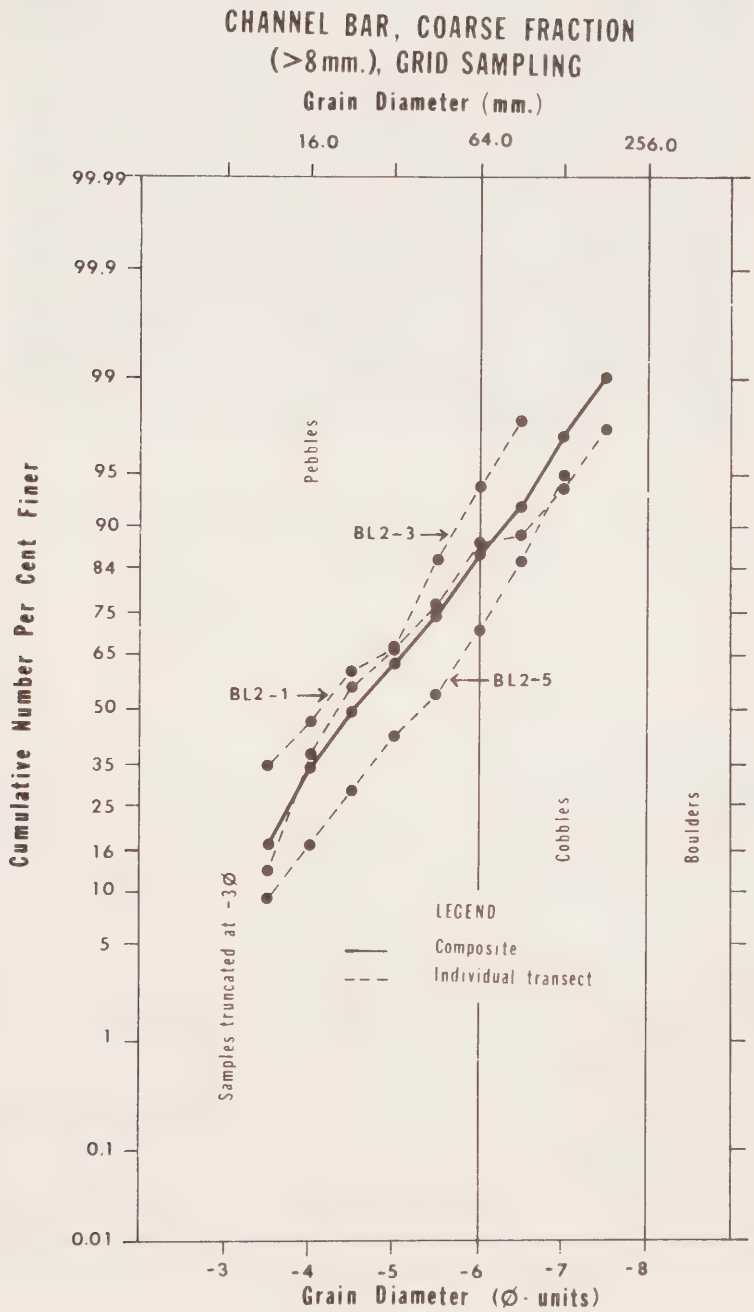



Figure BL2:4 Grain-size of surface fluvial sediment, reach BL2.

Figure BL2:5A Bedrock along channel margin, reach BL2, view downstream. (24 July 1972; GSC 202261-D).

Figure BL2:5B Thickly vegetated terrace remnant on west side of valley plain downstream from BL2-1, view downstream, reach BL2. (24 July 1972; GSC 202263-D).

(see also Figures 18 and 29 in text)

Yukon North Slope Rivers - Hydraulic Data

Reach: Blow River, BL2 Date: 25 Jul 72

a. Grain-size Statistics:

| | mm. | $\phi$ |
|---|---|---|
| $D_m$ | 25.1 | -4.65 |
| $D_{So}$ | | 1.18 (poor) |
| $D_{Sk}$ | | 0.134 |
| $D_K$ | | 0.902 |

b. Field Hydraulic Data: mean of 5 cross-sections

| Channel No. | |
|---|---|
| Q (m.$^3$/sec.) | 23.1 |
| $\bar{v}$ (m./sec.) | 0.795 |
| Fr | 0.271 |
| $W_s$ (m.) | 33.1 |
| P (m.) | 34.9 |
| $\bar{d}$ (m.) | 0.879 |
| R (m.) | 0.834 |
| A (m.$^2$) | 29.1 |
| $S_W$ | 0.000767 |
| $c_s$ (mg./l.) | 1 |
| $c_c$ (mg./l.) | 72 |
| T ($^o$C) | 11.9 |

c. Channel Geometry at Estimated Bankfull Stage: mean of 3 cross-sections

| Channel No. | 1 |
|---|---|
| $W_{sd}$ (m.) | 87.3 |
| $P_d$ (m.) | 91.1 |
| $\bar{d}_d$ (m.) | 1.88 |
| $R_d$ (m.) | 1.80 |
| $A_d$ (m.) | 164 |
| $S_V$ | - |
| $S_M$ | 0.00106 |

Blow River, reach BL3


Figure BL3:1. Blow River, Reach BL3 (Photo A21826-158; 1970).

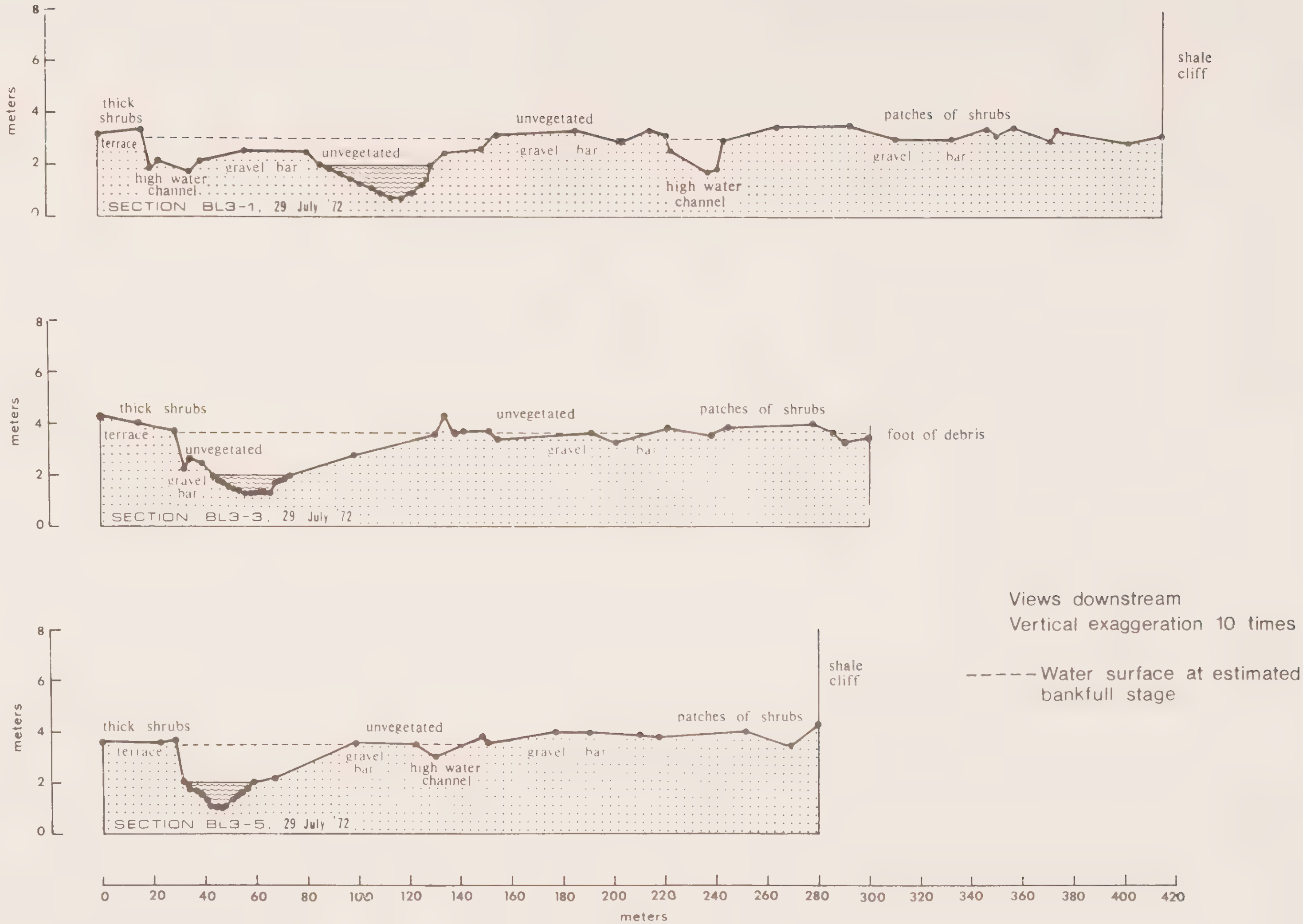



Figure BL3:2 Cross-sections, reach BL3

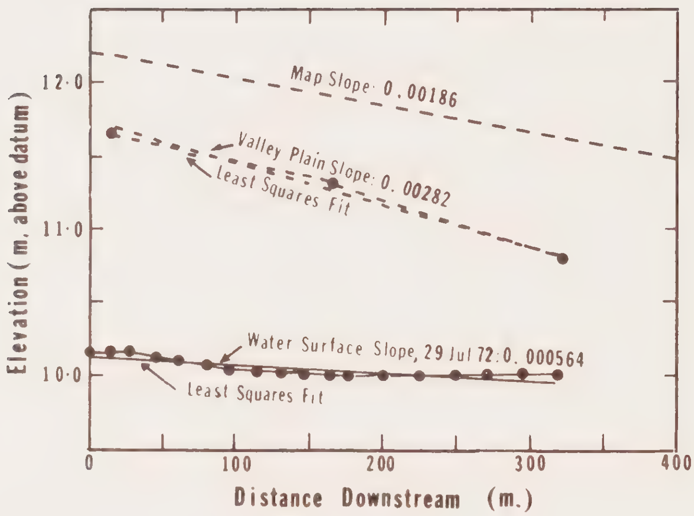
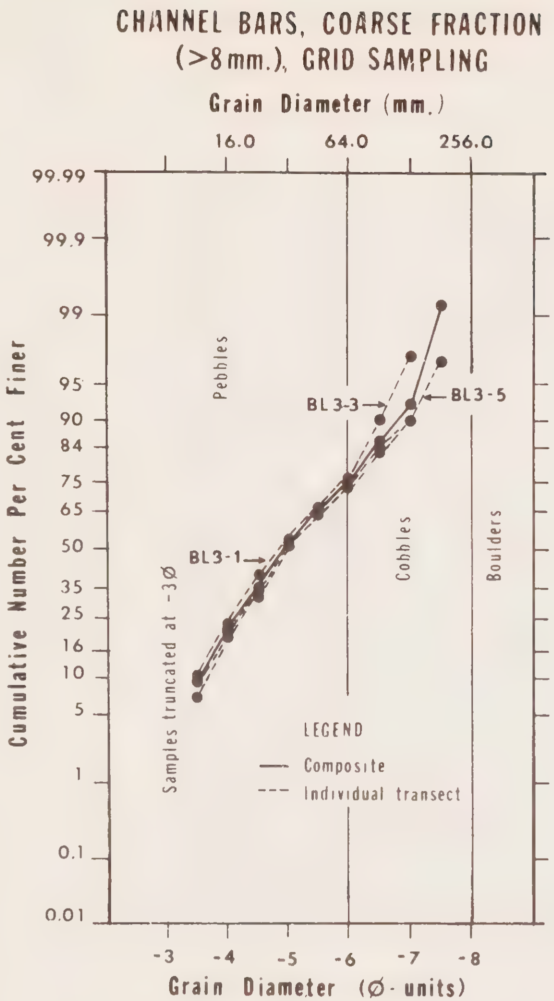



Figure BL3:3 Water surface, valley plain and map slopes, reach BL3.



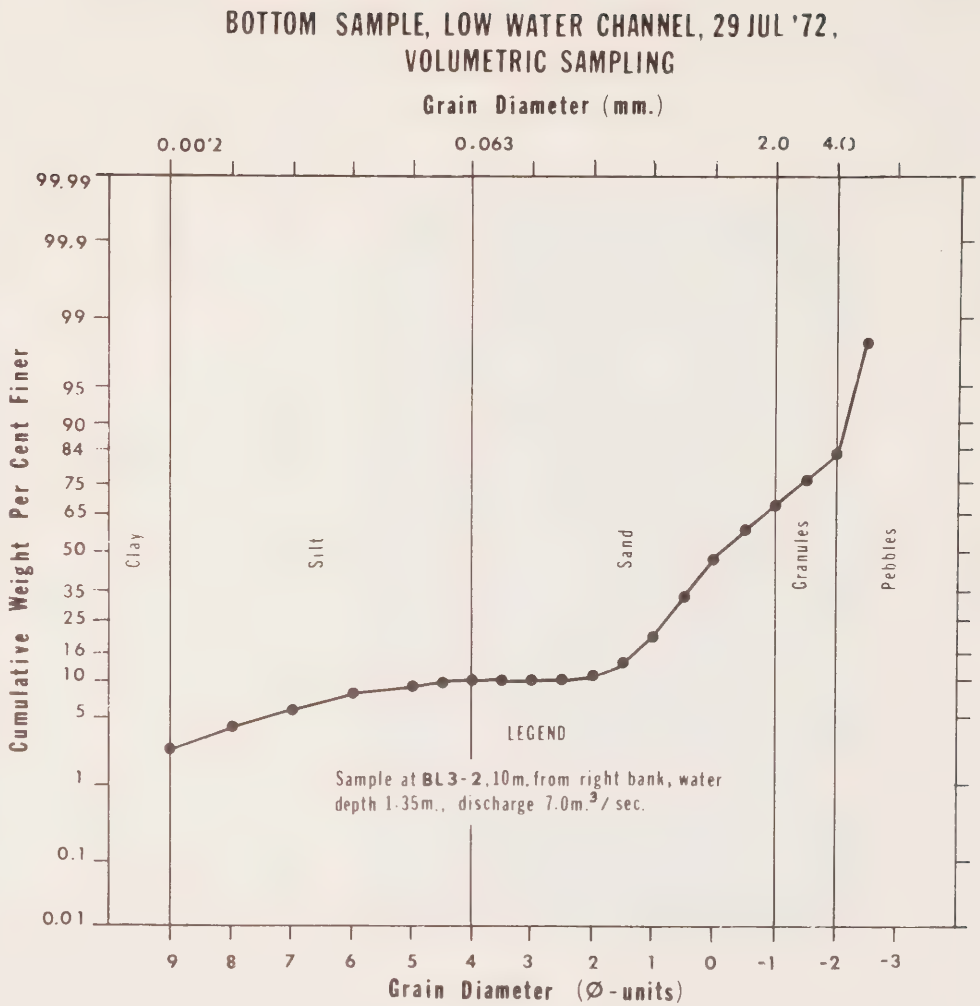




Figure BL3:4 Grain-size of surface fluvial sediment, reach BL3.

Figure BL3:5A Reach BL3 middle distance, view downstream (29 July 1972; GSC 202262-T).

Figure BL3:5B Fine-grained terrace sediment overlying cobbles in channel bank; reach BL3 looking downstream. (29 July 1972; GSC 202261-E).

Yukon North Slope Rivers - Hydraulic Data

Reach: Blow River, BL3 — Date: 29 Jul 72

a. Grain-size Statistics:

| | mm. | $\phi$ |
|---|---|---|
| $D_m$ | 33.1 | -5.05 |
| $D_{So}$ | | 1.23 (poor) |
| $D_{Sk}$ | | 0.116 |
| $D_K$ | | 0.853 |

b. Field Hydraulic Data: mean of 5 cross-sections

| Channel No. | |
|---|---|
| Q (m.$^3$/sec.) | 6.99 |
| $\bar{v}$ (m./sec.) | 0.306 |
| Fr | 0.121 |
| $W_s$ (m.) | 35.0 |
| P (m.) | 36.3 |
| $\bar{d}$ (m.) | 0.653 |
| R (m.) | 0.630 |
| A (m.$^2$) | 22.9 |
| $S_W$ | 0.000564 |
| $c_s$ (mg./l.) | 0 |
| $c_c$ (mg./l.) | 94 |
| T ($^o$C) | 13.7 |

c. Channel Geometry at Estimated Bankfull Stage: mean of 3 cross-sections

| Channel No. | 1 |
|---|---|
| $W_{sd}$ (m.) | 101 |
| $P_d$ (m.) | 103 |
| $\bar{d}_d$ (m.) | 1.08 |
| $R_d$ (m.) | 1.06 |
| $A_d$ (m.) | 109 |
| $S_V$ | - |
| $S_M$ | 0.00186 |

Blow River, reach BL4


Figure BL4:1. Blow River, Reach BL4 (Photo A22014-74; 1970).

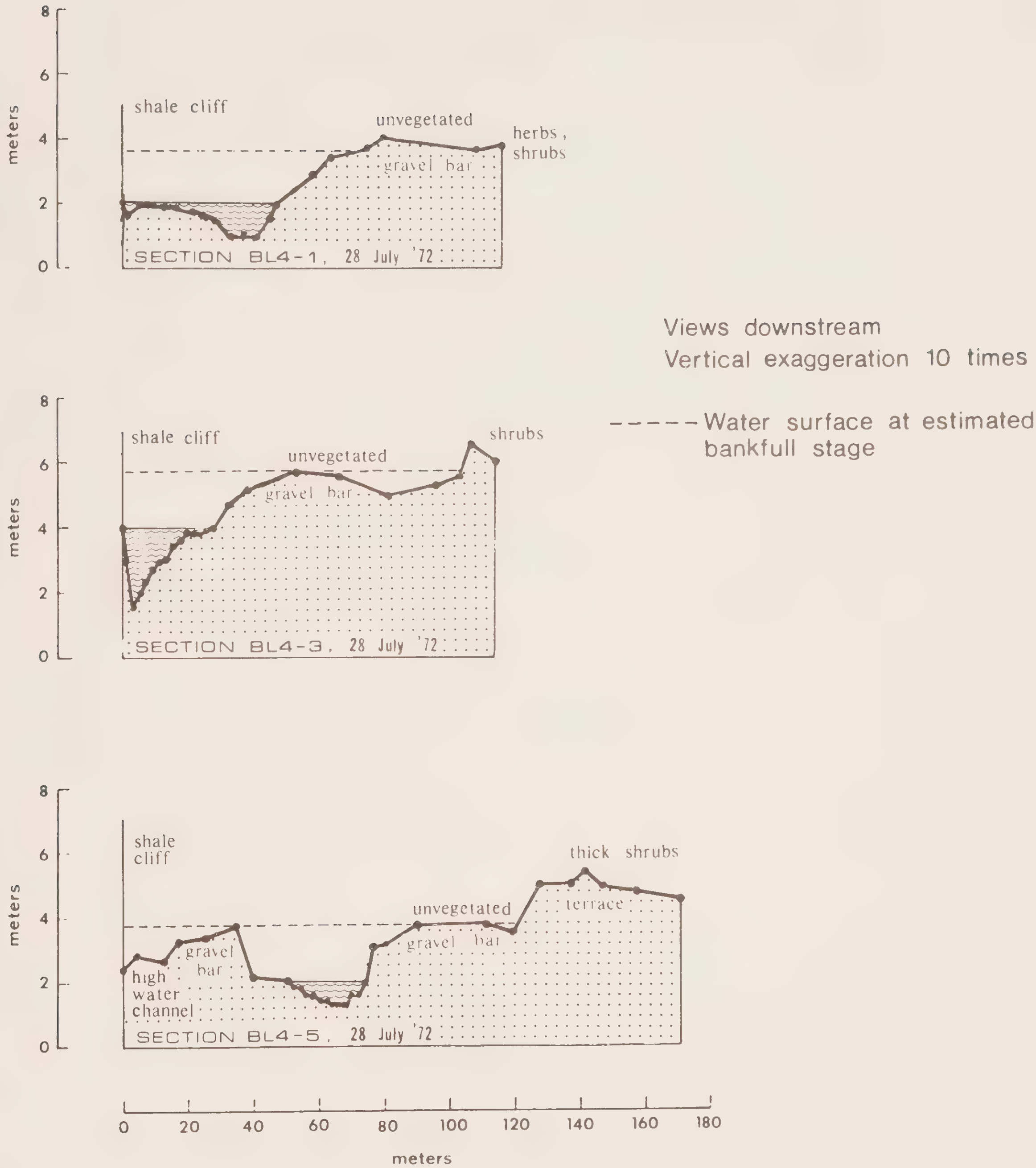



Figure BL4:2 Cross-sections, reach BL4

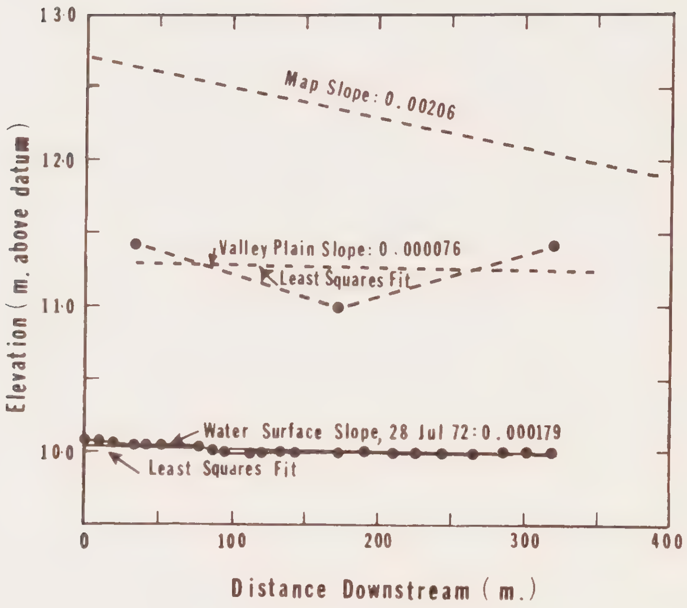



Figure BL4:3 Water surface, valley plain and map slopes, reach BL4.

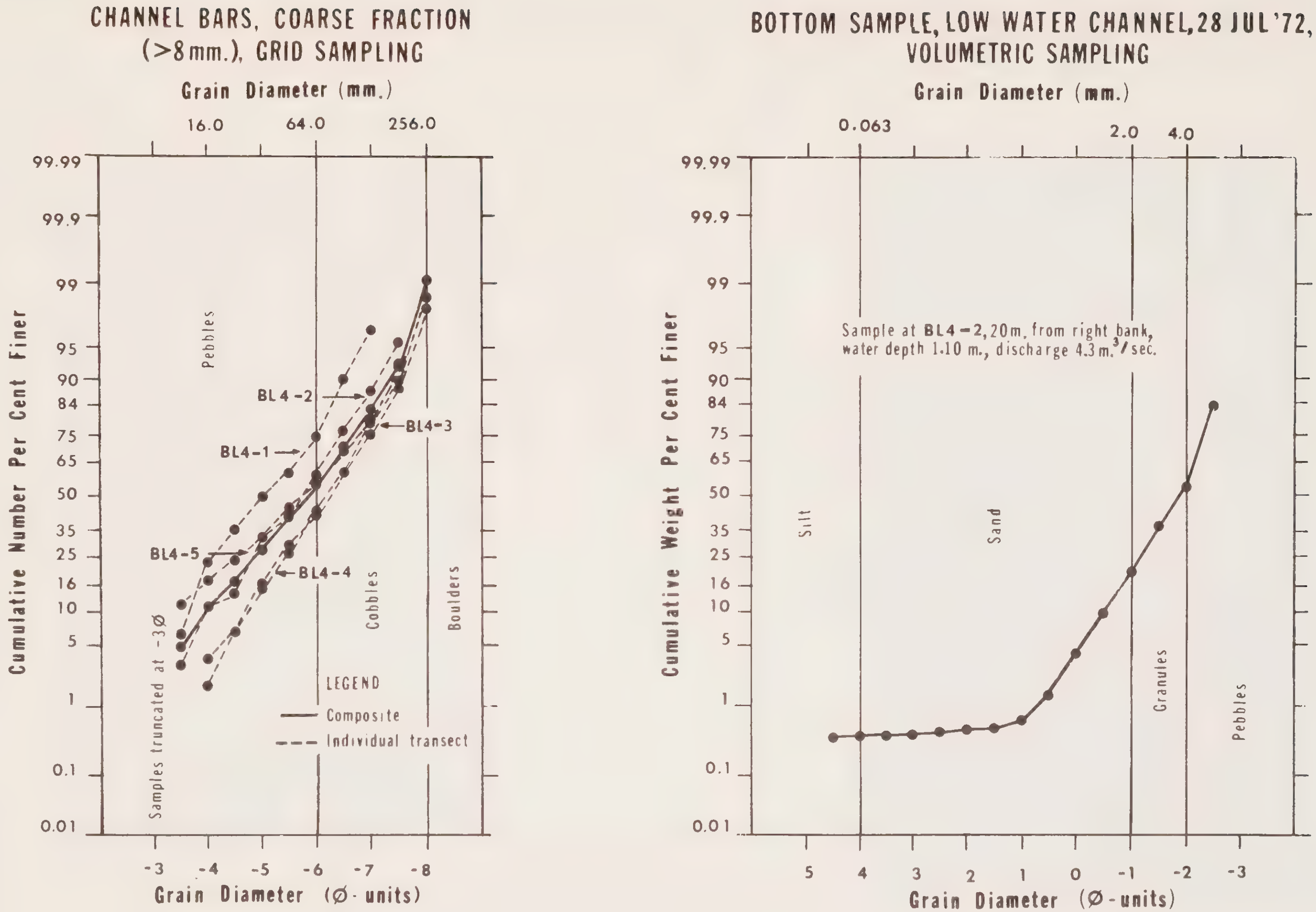



Figure BL4:4 Grain-size of surface fluvial sediment, reach BL4.

Figure BL4:5A Reach B14 in middle distance, view downstream. (28 July 1972; GSC 202263).

Figure BL4:5B Coarse gravel bar, reach BL4, view downstream. (28 July 1972; GSC 202263-G).

Yukon North Slope Rivers - Hydraulic Data

Reach: Blow River, BL4 Date: 28 Jul 72

a. Grain-size Statistics:

| | mm. | $\phi$ |
|---|---|---|
| $D_m$ | 55.7 | -5.80 |
| $D_{So}$ | | 1.289 (poor) |
| $D_{Sk}$ | | -0.136 |
| $D_K$ | | 0.922 |

b. Field Hydraulic Data: mean of 5 cross-sections

| Channel No. | |
|---|---|
| Q ($m.^3$/sec.) | 4.30 |
| $\bar{v}$ (m./sec.) | 0.205 |
| Fr | 0.0796 |
| $W_s$ (m.) | 31.0 |
| P (m.) | 32.4 |
| $\bar{d}$ (m.) | 0.676 |
| R (m.) | 0.648 |
| A ($m.^2$) | 21.0 |
| $S_W$ | 0.000179 |
| $c_s$ (mg./l.) | 3 |
| $c_c$ (mg./l.) | 84 |
| T (°C) | 14.5 |

c. Channel Geometry at Estimated Bankfull Stage: mean of 3 cross-sections

| Channel No. | 1 |
|---|---|
| $W_{sd}$ (m.) | 59.0 |
| $P_d$ (m.) | 62.2 |
| $\bar{d}_d$ (m.) | 1.60 |
| $R_d$ (m.) | 1.52 |
| $A_d$ (m.) | 94.6 |
| $S_V$ | - |
| $S_M$ | 0.00206 |

Blow River, reach BL5


Figure BL5:1. Blow River, Reach BL5 (Photo A21824-188; 1970).

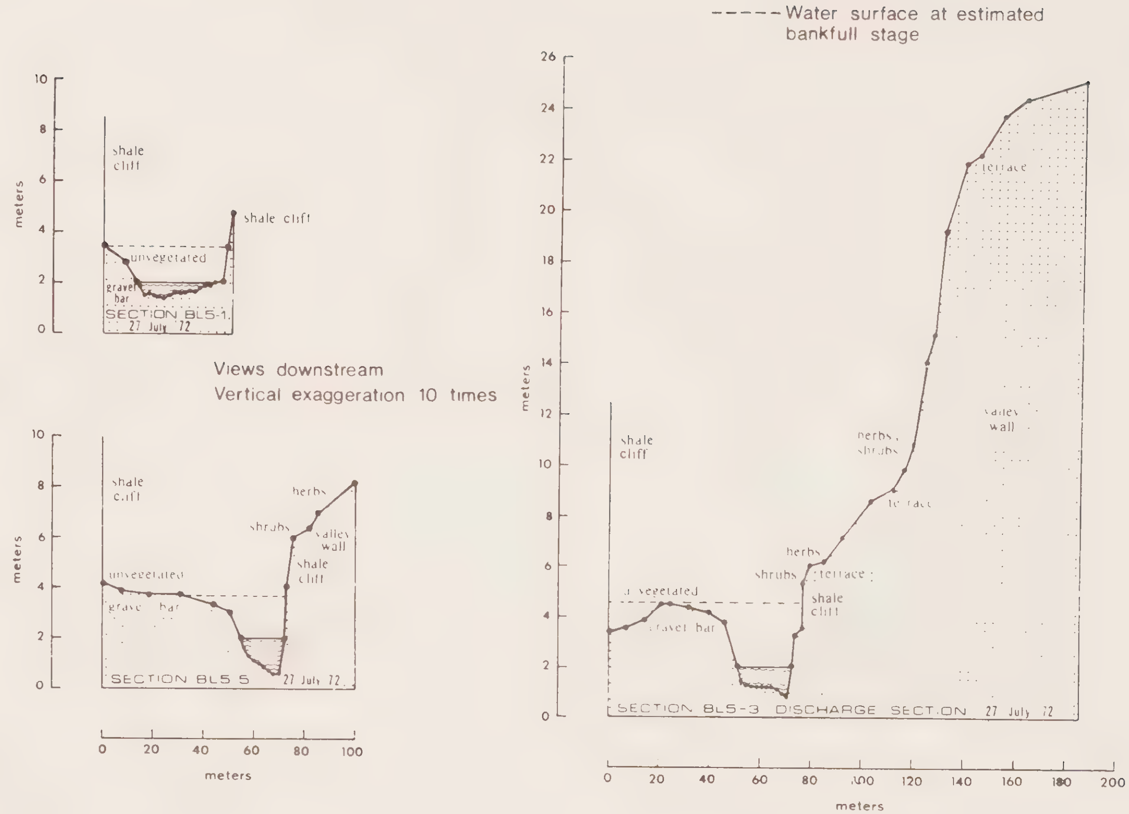



Figure BL5:2 Cross-sections, reach BL5

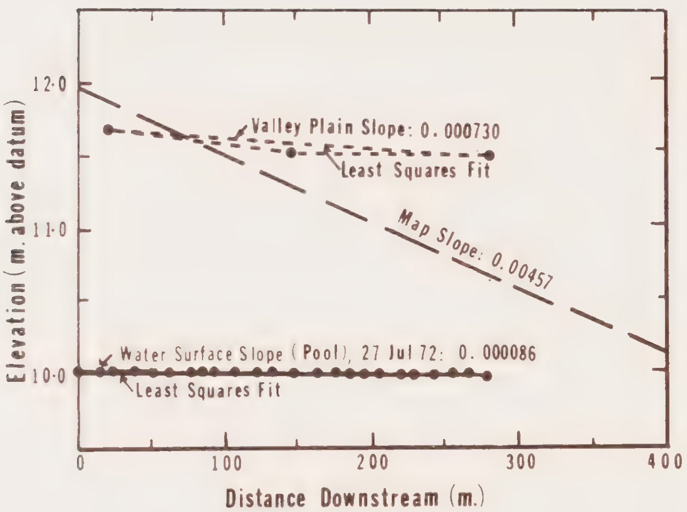



Figure BL5:3 Water surface, valley plain and map slopes, reach BL5.

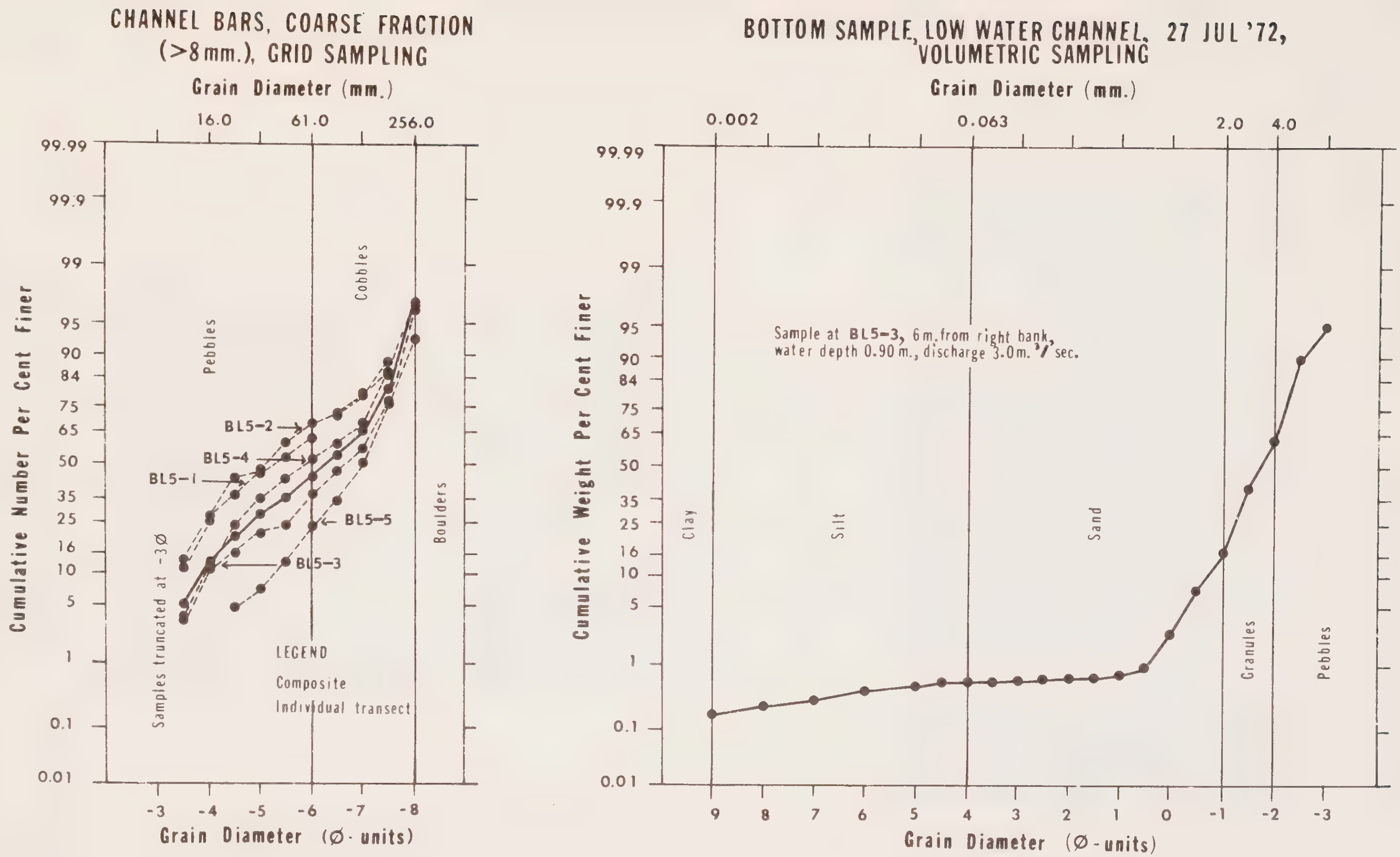



Figure BL5:4 Grain-size of surface fluvial sediment, reach BL5.

Figure BL5:5A Reach BL5 in middle distance; view downstream. (27 July 1972; GSC 202263-A).

Figure BL5:5B Painted line across coarse gravel bar, reach BL5. (27 July 1972; GSC 202262-U).

Yukon North Slope Rivers - Hydraulic Data

Reach: Blow River, BL 5 Date: 27 Jul 72

a. Grain-size Statistics:

| | mm. | $\phi$ |
|---|---|---|
| $D_m$ | 66.3 | -6.05 |
| $D_{So}$ | | 1.52 (poor) |
| $D_{Sk}$ | | -0.280 |
| $D_K$ | | 0.736 |

b. Field Hydraulic Data: mean of 5 cross-sections

| Channel No. | |
|---|---|
| Q (m.$^3$/sec.) | 2.95 |
| $\bar{v}$ (m./sec.) | 0.184 |
| Fr | 0.0713 |
| $W_s$ (m.) | 23.7 |
| P (m.) | 25.1 |
| $\bar{d}$ (m.) | 0.678 |
| R (m.) | 0.641 |
| A (m.$^2$) | 16.1 |
| $S_W$ | 0.0000860 |
| $c_s$ (mg./l.) | 1 |
| $c_c$ (mg./l.) | 102 |
| T ($^o$C) | 13.4 |

c. Channel Geometry at Estimated Bankfull Stage: mean of 3 cross-sections

| Channel No. | 1 |
|---|---|
| $W_{sd}$ (m.) | 44.0 |
| $P_d$ (m.) | 47.1 |
| $\bar{d}_d$ (m.) | 1.56 |
| $R_d$ (m.) | 1.46 |
| $A_d$ (m.) | 68.6 |
| $S_V$ | - |
| $S_M$ | 0.00457 |

Rapid Creek, reach R1

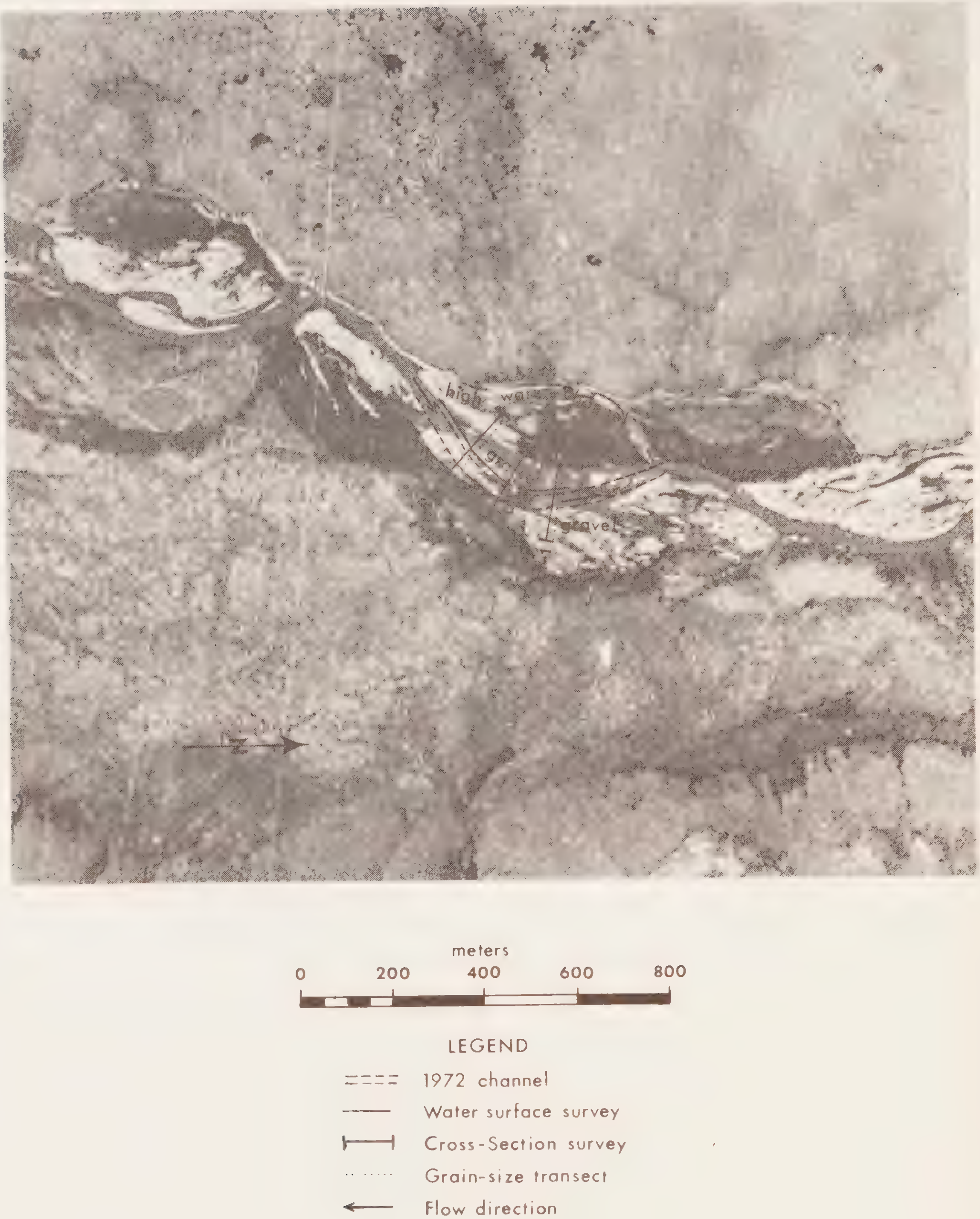



Figure R1:1. Rapid Creek, Reach R1 (Photo A15462-24; 1956).

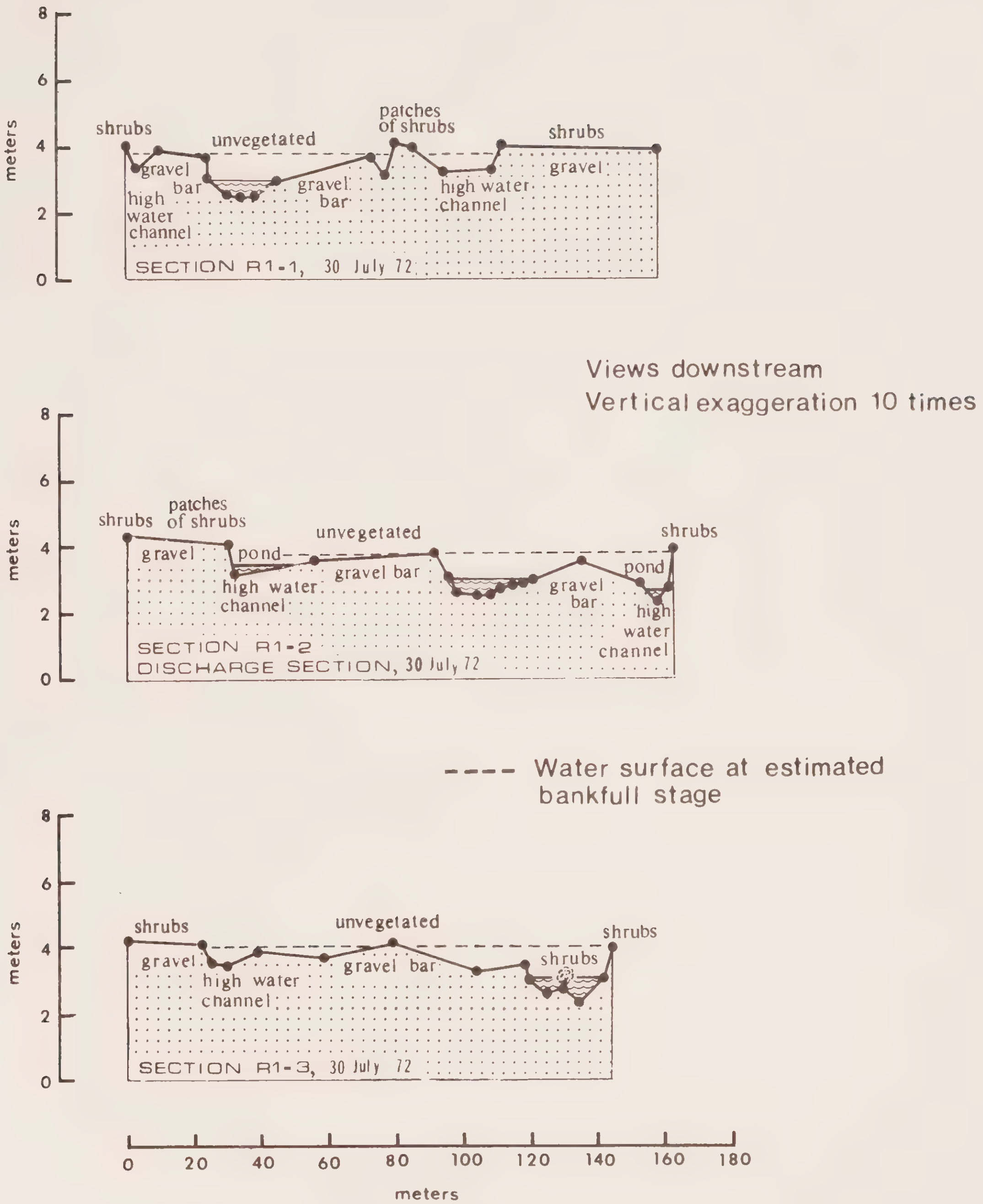



Figure R1:2 Cross-sections, reach R1

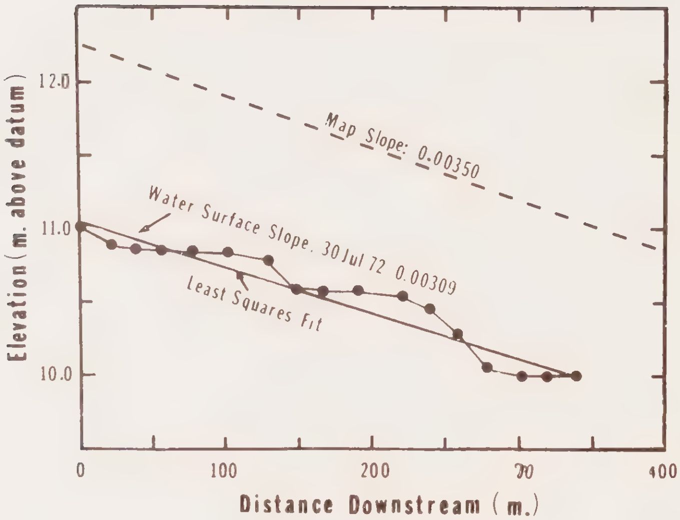



Figure R1:3 Water surface and map slopes, reach R1.

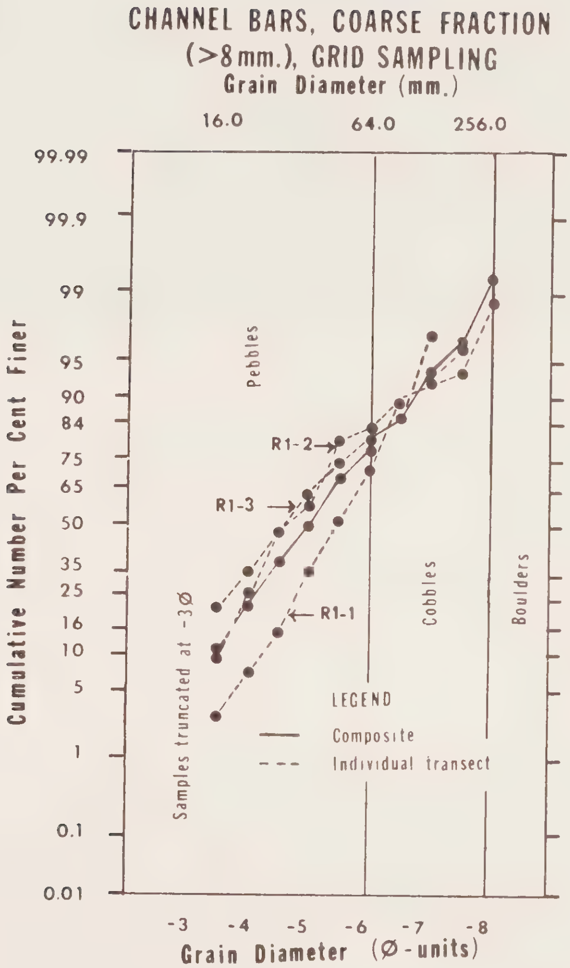



Figure R1:4 Grain-size of surface fluvial sediment, reach R1.

Figure R1:5A Reach R1, flow left to right.
(30 July 1972; GSC 202262-W).

Figure R1:5B Bar and bank characteristics near R1-3; view downstream, reach R1.
(30 July 1972; GSC 202263-H).

Yukon North Slope Rivers - Hydraulic Data

Reach: Rapid Creek, R1 Date: 30 Jul 72

a. Grain-size Statistics:

| | mm. | $\phi$ |
|---|---|---|
| $D_m$ | 34.3 | -5.10 |
| $D_{So}$ | | 1.28 (poor) |
| $D_{Sk}$ | | 0.0181 |
| $D_K$ | | 1.00 |

b. Field Hydraulic Data: mean of 1 cross-sections

| Channel No. | |
|---|---|
| Q ($m.^3$/sec.) | 3.81 |
| $\bar{v}$ (m./sec.) | 0.435 |
| Fr | 0.242 |
| $W_s$ (m.) | 26.5 |
| P (m.) | 27.2 |
| $\bar{d}$ (m.) | 0.330 |
| R (m.) | 0.322 |
| A ($m.^2$) | 8.75 |
| $S_W$ | 0.00309 |
| $c_s$ (mg./l.) | 8 |
| $c_c$ (mg./l.) | 124 |
| T (°C) | 12.4 |

c. Channel Geometry at Estimated Bankfull Stage: mean of 3 cross-sections

| Channel No. | 1 | 2 |
|---|---|---|
| $W_{sd}$ (m.) | 34.0 | 59.7 |
| $P_d$ (m.) | 34.7 | 61.5 |
| $\bar{d}_d$ (m.) | 0.368 | 0.896 |
| $R_d$ (m.) | 0.360 | 0.870 |
| $A_d$ (m.) | 12.5 | 53.5 |
| $S_V$ | - | |
| $S_M$ | 0.00350 | |

Big Fish River, reach BF1


Figure BF1:1. Big Fish River, Reach BF1 (Photo A14361-45; 1951-54).

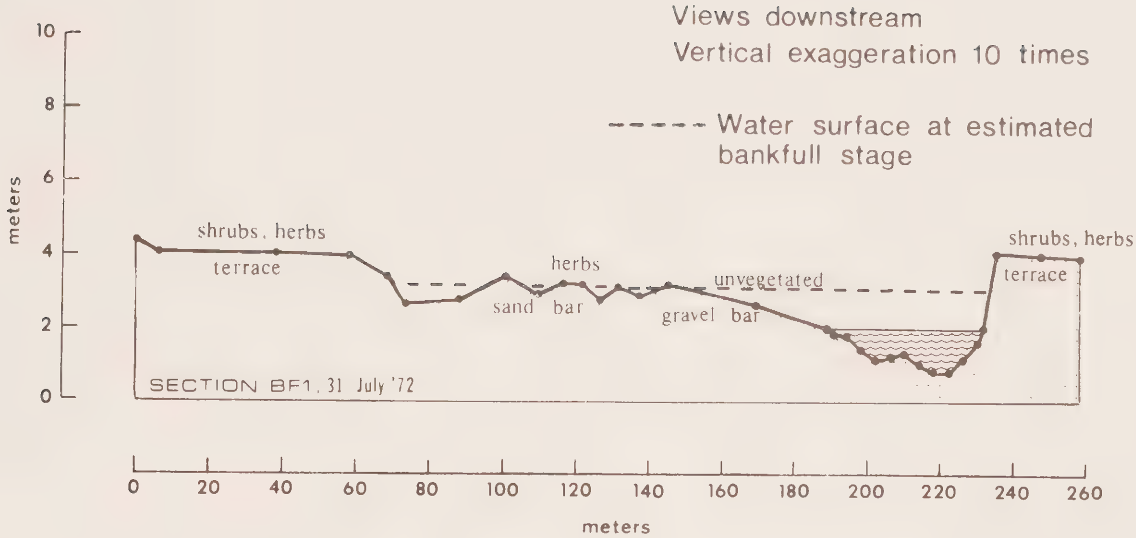



Figure BF1:2 Cross-section, reach BF1

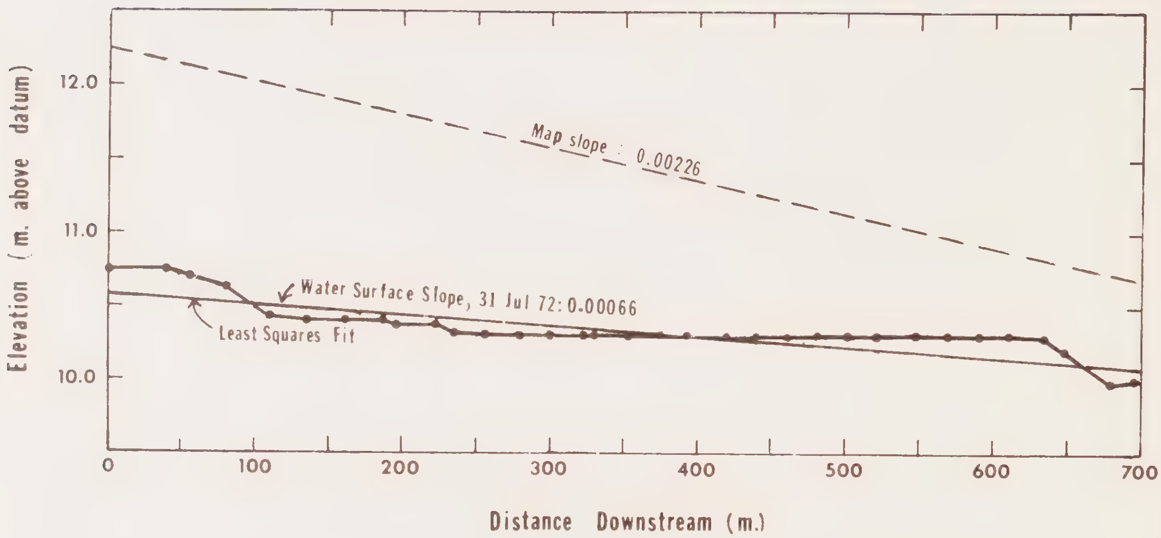



Figure BF1:3 Water surface and map slopes, reach BF1.

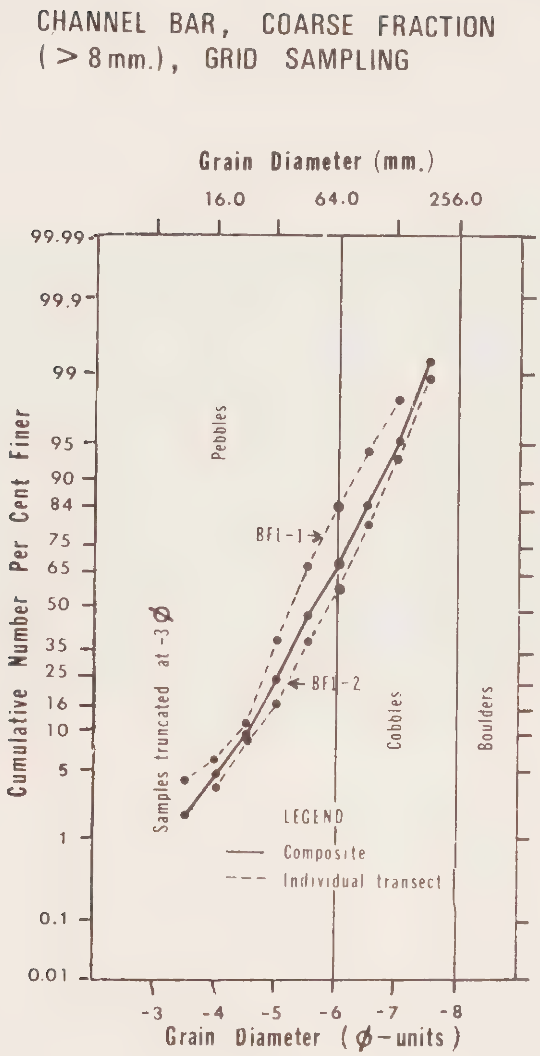



Figure BF1:4 Grain-size of surface fluvial sediment, reach BF1.

Figure BF1:5 Reach BF1 in left foreground; view upstream. (31 July 1972; GSC 202262-V).

Yukon North Slope Rivers - Hydraulic Data

Reach: Big Fish River, BF1 Date: 31 Jul 72

a. Grain-size Statistics:

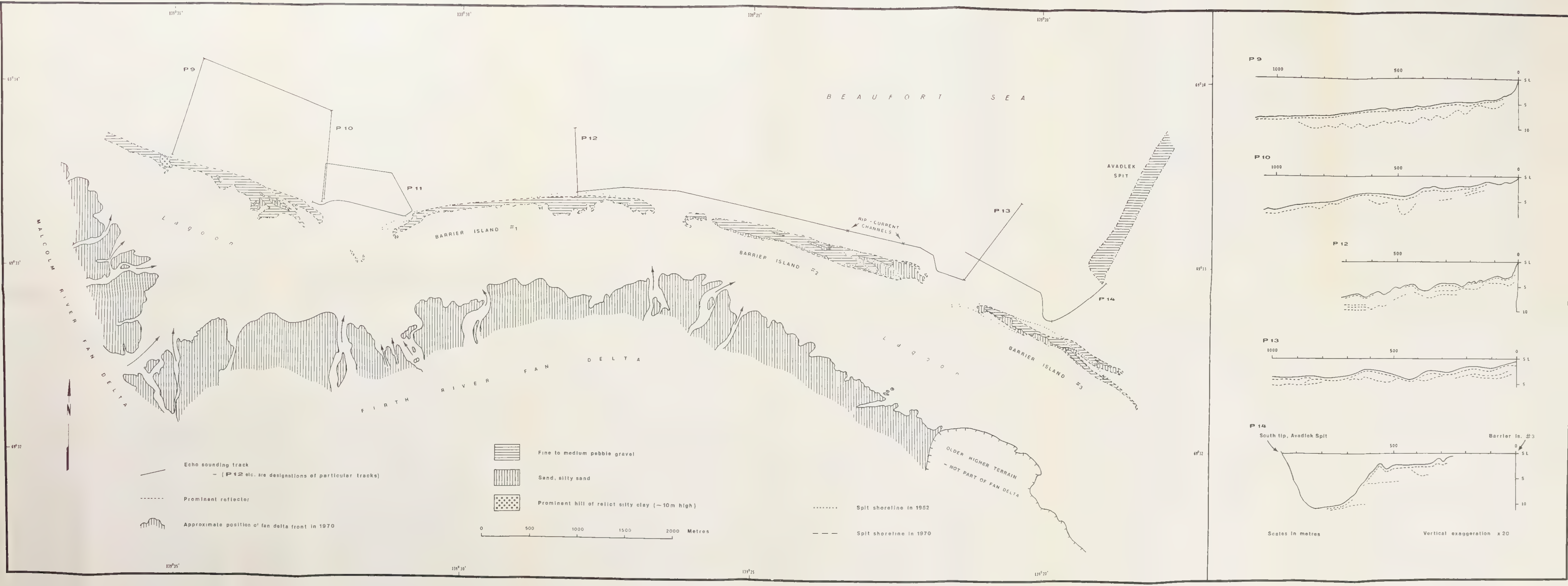
| | mm. | $\phi$ |
|---|---|---|
| $D_m$ | 49.5 | -5.63 |
| $D_{So}$ | | 0.864 (moderate) |
| $D_{Sk}$ | | 0.0122 |
| $D_K$ | | 1.03 |

b. Field Hydraulic Data: mean of 1 cross-sections

| Channel No. | |
|---|---|
| Q (m.$^3$/sec.) | 7.74 |
| $\bar{v}$ (m./sec.) | 0.266 |
| Fr | 0.103 |
| $W_s$ (m.) | 43.0 |
| P (m.) | 44.4 |
| $\bar{d}$ (m.) | 0.678 |
| R (m.) | 0.657 |
| A (m.$^2$) | 29.2 |
| $S_w$ | 0.00066 |
| $c_s$ (mg./l.) | 21 |
| $c_c$ (mg./l.) | 316 |
| T ($^o$C) | 14.8 |

c. Channel Geometry at Estimated Bankfull Stage: mean of 1 cross-sections

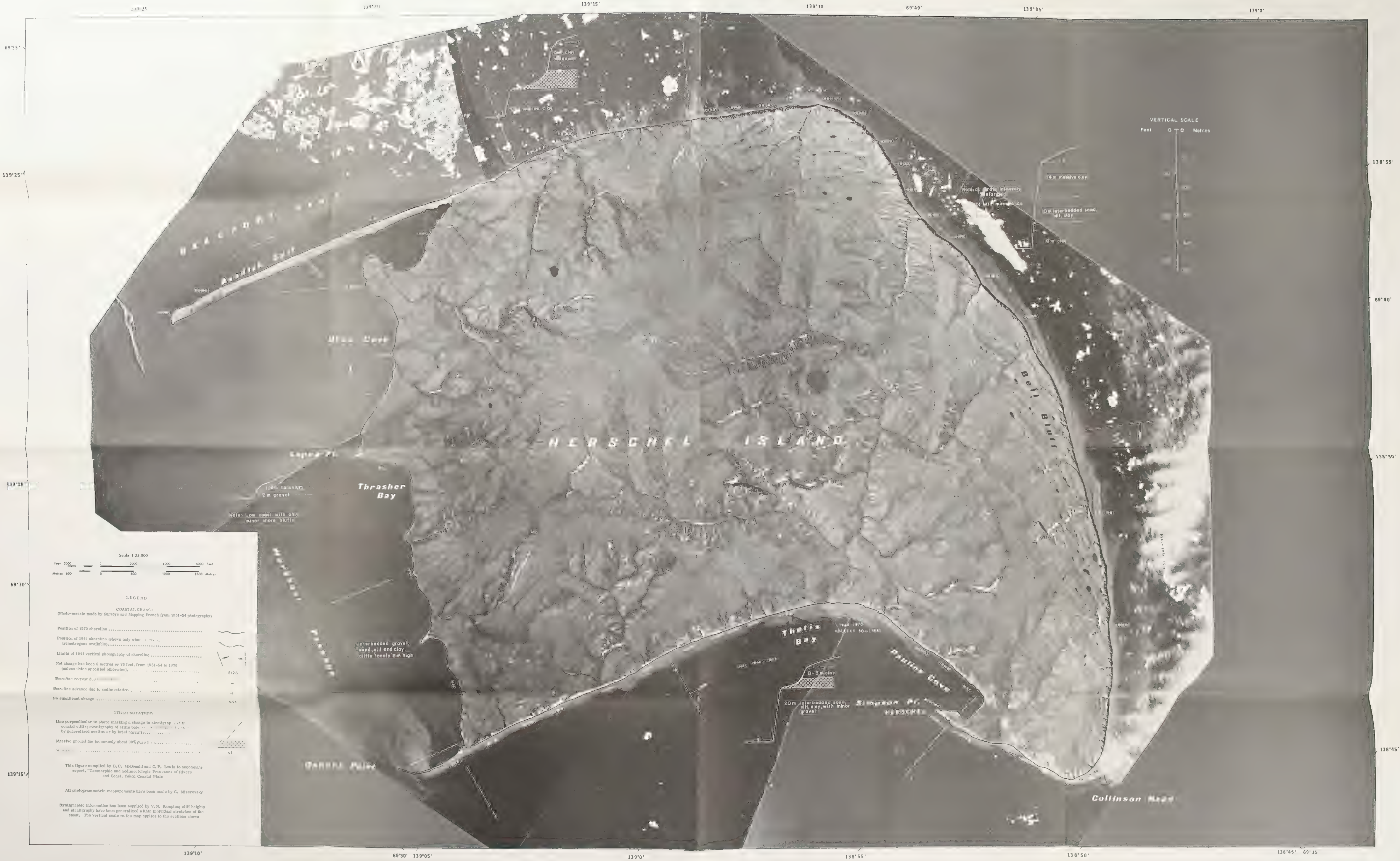
| Channel No. | 1 |
|---|---|
| $W_{sd}$ (m.) | 82.0 |
| $P_d$ (m.) | 84.5 |
| $\bar{d}_d$ (m.) | 1.26 |
| $R_d$ (m.) | 1.22 |
| $A_d$ (m.) | 103 |
| $S_V$ | - |
| $S_M$ | 0.00226 |




MAP NO. 6. NUNALUK SPIT

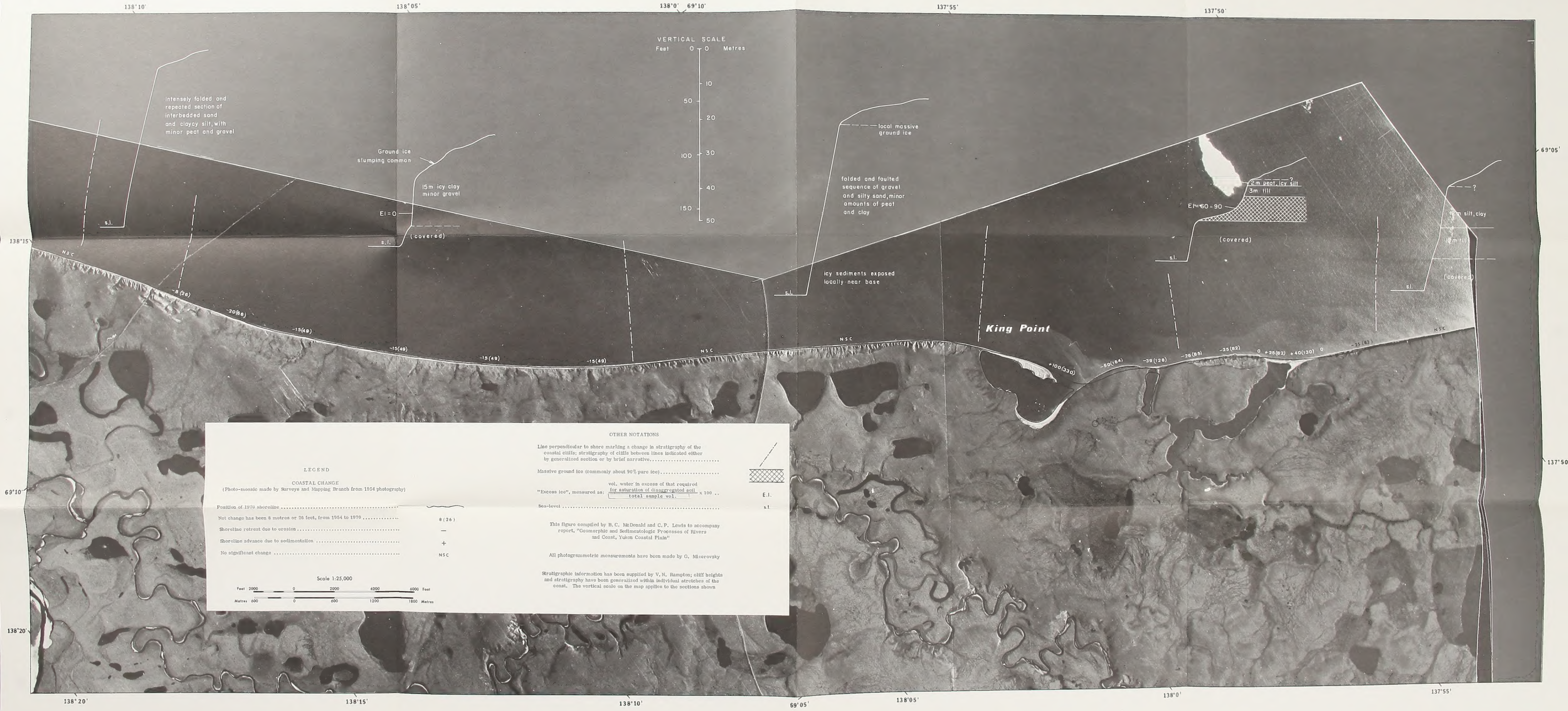

**MAP NO.4**

**PHILLIPS BAY - KAY POINT - BABBAGE BIGHT : COASTAL CHANGE 1944 - 1970**




**MAP NO.3**

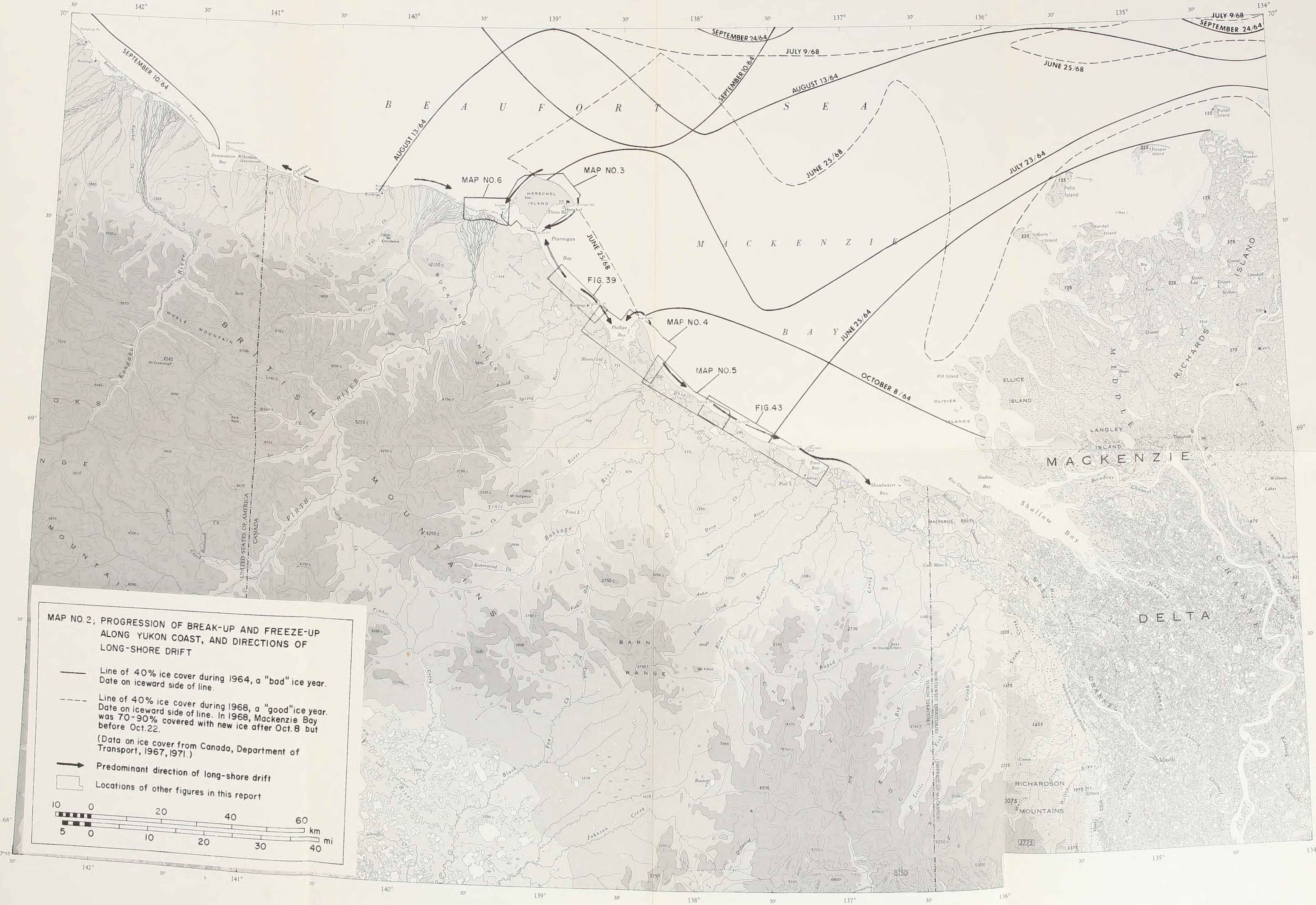
**HERSCHEL ISLAND: COASTAL CHANGE 1944 - 1970**




# MAP NO.5

# KING POINT: COASTAL CHANGE 1954 - 1970


MAP NO.1; RIVER BASINS, YUKON COASTAL PLAIN
Boundary of major drainage basin
Boundary of sub-basin
Maximum extent of Laurentide ice (hachures on unglaciated side)
Location of study reach
km
mi
BEAUFORT SEA
MACKENZIE BAY
HERSCHEL ISLAND
CRAIG CREEK
UNNAMED "A"
BACKHOUSE RIVER
FISH CREEK
MALCOLM RIVER
FIRTH RIVER
UNNAMED "B"
ROLAND CREEK
SPRING RIVER
UNNAMED "C"
CROW RIVER
TRAIL RIVER
BABBAGE RIVER
DEEP CREEK
RUNNING RIVER
BLOW RIVER
RAPID CREEK
EAGLE CREEK
BIG FISH RIVER
LITTLE FISH CREEK
M1
F1
F2
WSC
B1
B2
B3
B4
B5
RU1
BL1
BL2
BL3
BL4
BL5
R1
BF1
BRITISH MOUNTAINS
RICHARDSON MOUNTAINS
BARN RANGE
MACKENZIE DELTA
ELLICE ISLAND
LANGLEY ISLAND
RICHARDS ISLAND
UNITED STATES OF AMERICA
CANADA
ALASKA
YUKON TERRITORY
NORTHWEST TERRITORIES


MAP NO. 2; PROGRESSION OF BREAK-UP AND FREEZE-UP ALONG YUKON COAST, AND DIRECTIONS OF LONG-SHORE DRIFT
Line of 40% ice cover during 1964, a "bad" ice year. Date on iceward side of line.
Line of 40% ice cover during 1968, a "good" ice year. Date on iceward side of line. In 1968, Mackenzie Bay was 70-90% covered with new ice after Oct. 8 but before Oct. 22.
(Data on ice cover from Canada, Department of Transport, 1967, 1971.)
Predominant direction of long-shore drift
Locations of other figures in this report
km
mi
BEAUFORT SEA
MACKENZIE BAY
SEPTEMBER 10/64
AUGUST 13/64
SEPTEMBER 24/64
JULY 9/68
JUNE 25/68
JULY 23/64
OCTOBER 8/64
MAP NO. 6
MAP NO. 3
MAP NO. 4
MAP NO. 5
FIG. 39
FIG. 43
HERSCHEL ISLAND
BRITISH MOUNTAINS
BUCKLAND HILLS
RICHARDSON MOUNTAINS
BARN RANGE
MACKENZIE DELTA
ELLICE ISLAND
LANGLEY ISLAND
RICHARDS ISLAND
UNITED STATES OF AMERICA
CANADA
YUKON TERRITORY
NORTHWEST TERRITORIES